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ESMAP

Energy Sector Management Assistance Programme

# India

## Mini-Hydro Development on Irrigation Dams and Canal Drops Pre-Investment Study

## Volume I: Main Report

Report No. 139A/91

## JOINT UNDP/WORLD BANK

## ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME (ESMAP)

### PURPOSE

The Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP) was launched in 1983 to complement the Energy Assessment Programme which had been established three years earlier. An international Commission was convened in 1990 to address the creation of ESMAP's role in the Nineties. It concluded that the Programme had a crucial part to play over the next decade in assisting the developing countries to better manage their energy sectors given that the supply of energy at reasonable prices is a critical determinant of the pace and magnitude of the growth process. The Commission's recommendations received broad endorsement at the November 1990 ESMAP Annual Meeting. Today, ESMAP is carrying out energy assessments, preinvestment and prefeasibility activities and is providing institutional and policy advice. The program aims to strengthen the impact of bilateral and multilateral resources and private sector investment through providing technical assistance to the energy sector of developing countries. The findings and recommendations emerging from ESMAP activities provide governments, donors, and potential investors with the information needed to identify economically and environmentally sound energy projects and to accelerate their preparation and implementation.

ESMAP's operational activities are managed by two Divisions within the Industry and Energy Department at the World Bank and an ESMAP Secretariat.

- The Programme's activities are governed by the ESMAP Consultative Group which consists of its co-sponsors, the UNDP and the World Bank, the governments which provide financial support and representatives of the recipients of its assistance. The Chairman of the Group is the World Bank's Vice President, Sector Policy and Research. He is assisted by a Secretariat headed by the Group's Executive Secretary who is also responsible for relations with the donors and securing funding for the Programme's activities. The Secretariat also gives support and advice to a Technical Advisory Group of independent energy experts which meets periodically to review and scrutinize the Programme's strategic agenda, its work program and other issues related to ESMAP's functioning.

- The ESMAP Strategy and Programs Division is responsible for advising on which countries should receive ESMAP assistance, preparing relevant ESMAP programs of technical assistance to these countries and supports the Secretariat on funding issues. It also carries out broadly based studies such as energy assessments.

- The ESMAP Operations Division is responsible for the detailed design and implementation of tasks consisting mainly of sub-sectoral strategy formulation, preinvestment work, institutional studies, technical assistance and training within the framework of overall ESMAP country assistance programs.

### FUNDING

The ESMAP represents a cooperative international effort supported by the World Bank, the United Nations Development Programme and other United Nations agencies, the European Community, Organization of American States (OAS), Latin American Energy Organization (OLADE), and a number of countries including Australia, Belgium, Canada, Denmark, Germany, Finland, France, Iceland, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Sweden, Switzerland, the United Kingdom and the United States.

### FURTHER INFORMATION

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# INDIA

## Mini-Hydro Development

## on

## Irrigation Dams and Canal Drops

## Pre-Investment Study

### Volume I: Main Report

July 1991

## Currency Equivalents

Currency Unit = Rupees (Rs.)
Rs. 1.00 = Paise 100
1 US Dollar = Rs. 17.90
Rate as of September 1990

## Fiscal Year

April 1 - March 31

## Measures and Equivalents

| | | |
|---|---|---|
| 1 cumec | = | 1 cubic meter per second |
| 1 Kilowatt-hour (kWh) | = | 1,000 watt-hours |
| 1 Gigawatt-hour | = | 1 million kilowatt-hours |
| 1 kilovolt (kV) | = | 1000 volts |
| 1 kilovolt-ampere (kVA) | = | 1000 volt-amperes |
| 1 Meter (m) | = | 39.37 inches (in) |
| 1 kilometer (km) | = | 1000 meters (0.6214 miles) |

## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| APSEB | Andhra Pradesh State Electricity Board |
| CEA | Central Electricity Authority |
| COSTBEN | Cost Benefit Analysis Computer Program |
| DNES | Department of Non-Conventional Energy Sources |
| EIRR | Economic Internal Rates of Return |
| GOI | Government of India |
| IREDA | Indian Renewable Energy Development Agency |
| KSEB | Kerala State Electricity Board |
| KPCL | Karnataka Power Company |
| NTPC | National Thermal Power Corporation |
| NPV | Net Present Value |
| PCCOSTAB | Cost Estimation Computer Program |
| PFC | Power Finance Corporation |
| PSEB | Punjab State Electricity Board |
| RCC | Reinforced Cement Concrete |
| REC | Rural Electrification Corporation |
| SEB | State Electricity Board |
| SCF | Standard Conversion Factor |
| TNEB | Tamil Nadu Electricity Board |

## TABLE OF CONTENTS

Page No.



**FIGURES:**



**BOXES:**



**ANNEXES:**

Page No.

**FLOWCHARTS/DIAGRAMS:**



**IBRD MAPS:**

# EXECUTIVE SUMMARY

## A. Purpose

1. The purpose of this pre-investment study was to review the design and economics of a series of irrigation based mini-hydro schemes in the States of Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu in the southern region, and Punjab in the northern region. The study was conducted by the Joint UNDP/World Bank Energy Sector Management Assistance Program (ESMAP), working in collaboration with the Department of Non-Conventional Energy Sources (DNES), the State Electricity Boards (SEBs) in Andhra Pradesh, Kerala, Punjab, and Tamil Nadu, and the Karnataka Power Corporation Limited (KPCL). The report presents the results of the study in terms of the techno-economic concepts that were applied to improve the designs, minimize investment requirements, and thereby enhance the economic merits of the schemes. The report concludes with a economic and financial evaluation of prospective schemes in each of the five states.

## B. Structure of Report

2. The main text of the report (Volume I) is structured as follows:

Chapter I: Introduces the pre-investment study, reviews the objectives and scope of the study, and presents a brief overview of the irrigation based mini-hydro prospects in the States of Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Punjab.

Chapter II: Reviews the methodology used for the conceptual design of the mini-hydro schemes and for standardization of equipment specifications.

Chapter III: Elaborates on the main considerations used to streamline the layout of civil works and the electrical switching and protection systems. The chapter ends with a summary of capital cost estimates for each scheme.

Chapter IV: Evaluates the economic viability of each of the mini-hydro schemes. The results are presented in terms of the economic internal rates of return, and the net present values at a 12% discount rate.

Chapter V: Evaluates the financial impact of the schemes on each state, assuming that mini-hydro "cost centers" would be established by SEBs and the goal would be to achieve economic cost recovery. Also, the rate of return on equity is evaluated for private companies that may be interested in acquiring leases to develop captive power operations based on some of the mini-hydro prospects.

Annexes : Contains additional data, information, and analysis for specific points that are highlighted in the main text.

Technical Supplement: Volume II contains a complete set of design data, graphs, technical drawings, photographs of sites, and Volume III presents the breakdown of cost estimates for each scheme within the five states.

## C. Background

*Overview*

3. In India, there is the general perception that mini-hydro schemes are economically unattractive investments which must be assigned a lower priority relative to the large conventional hydropower systems. Over the past decade, the pace of India's large conventional hydropower program has slowed down because of: (i) the lack of financial resources in the states with the greatest hydropower potential; (ii) the recurring and drawn out disputes over water rights between states; and (iii) environmental and resettlement issues associated with large schemes; and (iv) the limited technical resources to proceed simultaneously with the preparation of several large schemes. Recognizing that the above impediments do not usually arise with mini-hydro schemes, the GOI is re-evaluating the scope for increasing the contribution of mini-hydro schemes to the power development goals of the Eighth Plan.

4. In a recently completed review of the country's non-conventional energy program, ESMAP concluded that all the basic prerequisites for economically viable mini-hydropower generation exist at sites in India that are associated with irrigation water storage and distribution infrastructure (i.e., to harness the hydraulic energy created by discharges from irrigation dams and the flow of water across diversion weirs and canal drops). Compared to river based schemes, the cost of developing irrigation based mini-hydro schemes should be considerably lower because most of the civil works have already been constructed.

5. The ESMAP assessment emphasized that the potential for power generation with this category of mini-hydro application was significantly large in the country because of the extensive infrastructure for surface irrigation; since independence in 1947, the total area under irrigation in the country has increased from 19.5 million hectares to over 70 million hectares. In the mid-1980s, the Rural Electrification Corporation (REC) conducted a survey to obtain data and information on the potential for power generation on existing irrigation systems in the country. The information supplied by the State Electricity Boards (SEBs) indicated that over a thousand sites associated with existing irrigation dams, diversion weirs, and canal drops were among the most prospective sites for mini-hydropower development. The REC survey highlighted the concentration of prospects in the southern region, especially in the States of Andhra Pradesh, Karnataka, and Tamil Nadu where over 500 sites with the potential to produce 2000 GWh annually had been identified.

5. Despite the initial assessment by ESMAP, there still are doubts within the GOI about the economic viability of irrigation based mini-hydro schemes. These doubts persist because the average costs of developing pilot schemes in several states had exceeded Rs. 30,000 per kW installed in 1988 prices. Following the transfer of responsibility of mini-hydro schemes (up to 3 MW capacity) from the Department of Power (DOP) to the DNES, a multi-agency Sub-Committee on Mini-Hydropower was convened to formulate a strategy to improve the cost-effectiveness of mini-hydro programs in general, and to review proposals for the Eight Five-Year Plan (1990-95). In parallel with the work of the Sub-Committee, the GOI through DNES requested ESMAP to assist further in critically evaluating proposals for new irrigation based mini-hydro schemes in several states, and if warranted by the findings, to address comprehensively the pre-investment requirements for a multi-scheme investment program for consideration by international and/or domestic financial institutions.

*Improving Cost-Effectiveness*

6. In response to the GOI request, ESMAP conducted a preliminary but critical examination of the available information and documentation on existing and proposed schemes. As a result, ESMAP identified three main shortcomings in the approach to irrigation based mini-hydro development in the country. First, the initial batch of schemes were conceived, designed, and executed as scaled down versions of large conventional hydro installations. Consequently, there are numerous redundancies in the designs for key features such as the layout of civil works, the facilities incorporated into the powerhouse structures, the selection of turbine-generator equipment, and the specification of electrical switching and protection systems. Second, due to the use of relatively complex layouts for the schemes, the gestation time to construct and commission the schemes has been unacceptably high. For example, it has taken over four years to complete the majority of the pilot schemes in the southern region. As a result of the slow pace of implementing the construction work, there has been a significant escalation in capital costs and in interest payments during construction. Third, the viability of the pilot schemes were being undermined by the use of unnecessarily large numbers of technical staff to operate and maintain the mini-hydro schemes. The GOI concurred with the preliminary findings of ESMAP; consequently ESMAP proceeded with the study.

**D. Objectives**

7. The principal objective of this study 1/ was to apply techno-economic criteria to improve the design and economic viability of irrigation based mini-hydro schemes, and to identify and prepare a medium term investment program to develop a series of irrigation based mini-hydro schemes in the southern region of India. Accordingly, the study covered previously identified and investigated sites in the States of Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu which have similar topography and irrigation regimes. At the request of the DNES, the scope of the study was expanded to include twelve prospective sites in the State of Punjab, all of which are earmarked for development under the mini-hydro component of the ongoing World Bank/IDA financed Punjab Irrigation and Drainage Project.

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1/ This activity was executed by an ESMAP team which comprised: Messrs. Amarquaye Armar (Senior Energy Planner, World Bank) the Team Leader; Alfonso Posada (Power Systems Consultant) the Principal Adviser; and Arcot. S. Chelvaraj (Hydropower Consultant), V. Sreenivasa Murthy (Electrical Engineering Consultant), and Robert A. Smith (Financial Analyst - Consultant). Messrs. Y. K. Murthy and A. N. Singh (Management Consultants), former Chief Executives of the Central Water Commission and the Central Electricity Authority, contributed to the review of institution building aspects of irrigation based mini-hydro development; Mr. Sivaguru Chelvaraj (Researcher) assisted the team by developing and applying specialized computer software to process the hydrological data into design curves (i.e., flow duration, head duration, and energy production curves) for each scheme; and Mr. Okorie Uchendu (Researcher) assisted on the application of the World Bank's PCCOSTAB and COSTBEN computer programs for the cost estimation and economic evaluation of schemes. The report was prepared by Messrs. A. Armar and A. Chelvaraj; the technical drawings were prepared by Mr. A. Chelvaraj and Ms. Yeshi Gonfa provided secretarial support. The report was reviewed and cleared by the GOI in June, 1991. The Government of Switzerland provided ESMAP with the funding for this activity.

8. The pre-investment study was structured to: (i) assess the technical and economic feasibility of developing between 10 to 20 prospects in each state, especially those that had already been investigated to at least the pre-feasibility stage by the respective SEBs; (ii) critically evaluate the cost-effectiveness of engineering designs and specifications that had been proposed by the SEBs, and to redesign each scheme to maximize the number of kilowatt hours produced annually per unit of investment; (iii) update and revise the estimates of the capital costs of developing the schemes, and to evaluate the economic and financial viability of establishing the schemes to provide energy and voltage support to the power grid in the respective states; (iv) explore the scope for achieving full cost recovery on all phases of mini-hydro development; (v) evaluate the financial returns that private companies and investors would realize by developing the schemes as alternative sources of captive generation; and (vi) prepare a comprehensive report which would define technical concepts and design methodology used for the study, the relative benefits and costs of the proposed program, investment requirements at the state level, and the financial impact of the proposed program on the states. Despite the focus on the southern region, the design methodology was also meant to be applicable in future to the preparation of similar investment programs in the other regions and states of the country.

### E. Prospects Studied

9. Irrigation based mini-hydro schemes in India are the exclusive focus of this study. In line with the DNES mandate, the original aim was to limit the scope of the study to irrigation based mini-hydro prospects which, on the basis of previous pre-feasibility studies, would provide up to 3 MW of installed capacity. However, on consultation with the SEBs about the approach to be used for the Study, there was a consensus that it would be more appropriate to relax the ceiling on capacity, and to review all irrigation based mini-hydro prospects for which a pre-feasibility report had already been prepared. Accordingly, ESMAP collaborated with the DNES and the SEBs to critically examine the original proposals and as necessary, to revise layouts and designs for schemes in order to enhance economic attractiveness. In all, over fifty mini-hydro prospects in the southern region were reviewed, comprising eighteen sites which are associated with irrigation dams, three sites which are located at either diversion weirs or barrages, and over thirty sites on ten branch canals, twenty-two of which could be developed as five cluster schemes. In addition, the study focused on twelve prospects in Punjab State which are located on the Sirhind and Bhakra Main Line Canals; all those

LIST OF MINI-HYDRO PROSPECTS STUDIED

| DAM BASED SCHEMES | CANAL DROP SCHEMES |
|---|---|
| ANDHRA PRADESH | ANDHRA PRADESH |
| Lower Manair Reservoir | Guntur BC Cluster(4) |
| | Adanki BC Cluster(2) |
| | Lock in Sula |
| KARNATAKA | Ongole BC Cluster(5) |
| Attehala | Sriramasagar Cluster (5) |
| Brindavan | |
| Devrebelerkere | KARNATAKA |
| Harangi | Anveri |
| Kabini | Kilara |
| Malaprabha | Maddur |
| Mudhol | Rajankollur |
| Nugu | Shahpur BC Cluster(6) |
| KERALA | PUNJAB |
| Mangalam | Abohar BC Cluster (4) |
| Maniyar | Bhatinda BC Cluster(2) |
| Peechi | Bhakra MC Cluster(2) |
| Kuttiyadi | Kotla BC Cluster (4) |
| TAMIL NADU | TAMIL NADU |
| Aliyar | Grand Anicut |
| Amaravathy | Tongkorai |
| Lower Bhavani | Tughlapatti |
| Peechiparai | Villampatti |
| Perunchani | Mettur WBC |
| Sathanur | |
| Thirumurthy | |
| Krishnagiri | |

Box 1

prospects are earmarked for development under the ongoing Punjab Irrigation and Drainage Project. Altogether, ten of the prospects would have an installed capacity greater than 3 MW; only five of those schemes (i.e, the Brindavan Dam scheme in Karnataka, the Maniyar Barrage scheme in Kerala, the Lower Bhavani (RBC) scheme in Tamil Nadu, and the canal drop schemes at Thablan and Chanarthal respectively in Punjab) would require mandatory technical clearance from the CEA because the estimated capital costs are equal to exceed Rs. 50 million.

### F. Design Approach

10. All the prospective mini-hydro schemes would be linked to the grid at 11/33 kV sub-stations. To be economically viable, each scheme must be able to produce energy at or below the marginal energy costs of generation in the grid. Furthermore, since irrigation operations must not be disrupted by the introduction of the mini-hydro schemes, the primary objective of design was to harness the optimal amount of energy from the existing pattern of irrigation discharges. Accordingly, the approach used in the study was to establish techno-economic criteria that would reflect the above requirements and operating constraints, and to use the criteria as the yardstick for evaluating and improving the original designs for each of the prospects.

*Economic Value of Energy Produced*

11. The economic viability of the irrigation based mini-hydro schemes was assessed in terms of their cost competitiveness relative to conventional sources of generation in the grid (i.e., from the least cost system development plan). Since India's power systems are planned and operated on a regional basis, the cost of generation from the proposed irrigation based mini-hydro schemes in the States of Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu were compared to the marginal costs of generation in the Southern Regional Grid, while those in Punjab were assessed in the context of the Northern Regional Grid.

12. Given the large sizes of the southern and northern regional grid systems, it is clear that none of the irrigation based mini-hydro schemes would be large enough to significantly affect the system development plans of the grids so as to require deferral of capacity expansion projects and/or a re-optimization of the use of existing thermal stations. Rather, the principal role of the irrigation based mini-hydro schemes would be to alleviate localized energy deficits by providing energy support to improve the quality of service in remote portions of the grid, thereby displacing higher cost energy supplies from thermal power stations and reducing the extent of standby diesel auto-generation by industrial and commercial establishments.

13. Accordingly, the economic value of the benefits of the mini-hydro schemes were derived in terms of the avoided costs of energy supply at the 33 kV level from the regional power grids. The high degree of congruity between the seasonal discharge of irrigation water and the seasonal variations in peak load within both regional grids, suggests that a capacity credit should be considered as an additional benefit of the proposed irrigation based mini-hydro schemes. However, given that the irrigation discharges are restricted to between nine to ten months each year, and that the SEBs do not have effective control of water flows even during those months of sustained operations, energy generation levels and capacity availability were considered to be "non-firm". Accordingly, capacity credits attributed to the proposed schemes were not quantified for the purposes of this evaluation which lends a conservative bias to the economic value of the benefits.

14. During off-peak hours of service, the avoided costs of energy supply from the grid consists of the fuel costs plus variable operating and maintenance expenses of the less efficient or

marginal stations in service (i.e, the short-run marginal costs of generation); the average of the avoided costs of energy supply from the grids was determined to be Rs. 0.55-0.60 per kWh, which after adjusting upwards to account for 15% T&D losses resulted in the estimate of Rs. 0.63-0.69 per kWh for the economic value of energy produced during off-peak periods by the irrigation based mini-hydro schemes. By contrast, during the periods of daily peak demand (about 5 hours), power outages are widespread and large numbers of industrial and commercial consumers resort to the use of standby diesel generators. Under those circumstances, the avoided costs of energy supply were estimated to be equivalent to the variable costs of auto-generation from stand-by diesel units that are operated by commercial (Rs. 1.31 per kWH) and Industrial (Rs. 1.16 per kWh) establishments. Combining the avoided costs of energy during the off-peak and peak periods, the composite value of the energy produced by the proposed irrigation based mini-hydro schemes was estimated to be of the order of Rs. 0.80 per kWh.

*Techno-Economic Design Criteria*

15. In designing economically viable irrigation based mini-hydro schemes, the primary objective is to maximize the number of kilowatt hours produced annually per unit of investment; this techno-economic criteria is referred to as the *annual energy productivity* of a given scheme. The robustness of the sizing procedure (i.e., maximizing *annual energy productivity*) was checked against the more elaborate analysis which calculated the B/C ratios for the incremental generation by each additional unit for prospective dam based schemes. The analysis confirmed that the energy productivity concept provides reliable and consistent techno-economic criteria for selecting the optimal the plant size.

16. During preliminary design, an iterative procedure was used to select and evaluate different configurations of multi-unit turbine-generators. Each configuration was screened to ensure that energy would be produced for Rs. 0.80/kWh or less; for design purposes, this required that each scheme would have to produce a minimum of 20.6 kWh annually per 100 Rs. invested to be competitive economically with power supply from the grid.

*Standardization of Designs*

17. To improve upon the original designs, considerable attention was given to identifying practical measures to minimize capital costs. For turbine-generator units, this was achieved by developing a set of standardized specifications according to available heads and discharges. As a result, a set of eight standardized specifications based on runner diameters were developed for the turbine requirements of all fifty-three schemes, ranging in diameter from 2800 mm. to 1000 mm (i.e., for fixed blade tubular turbines). Similarly, a set of eight standardized capacities were specified for the induction (asynchronous) generators; the minimum capacity was 350 kW and the maximum was 3500 kW. All redundant equipment and instruments that had previously been incorporated into the electrical protection and switching arrangements were eliminated. Standardized single line diagrams and electrical protection schemes were developed to cater to the requirements of all the fifty-three schemes. To minimize the costs of civil works, alternative layouts and designs of the main civil structures were re-defined and evaluated according to three criteria: (i) structural modifications to the existing irrigation facilities were reduced to a minimum; (ii) layouts of civil structures and electrical switching systems were streamlined to facilitate construction, so that schemes would be implemented within two irrigation seasons; and (iii) layouts were specified so as not to cause any permanent loss of productive agricultural land. To the extent possible for each category of mini-hydro scheme, a set of standard designs was developed for main civil structures, particularly the powerhouse structures, and the water intake and conveyance structures.

*Environmental Impacts*

18. Prior to developing the schemes, each of the SEBs will need to obtain the necessary clearances from agencies that are responsible for forestry and environmental protection at the central and state GOI levels. Accordingly the revised designs were reviewed to ensure that none of the schemes would have a negative impact on the environment or lead to the resettlement of nearby communities. Since the majority of the schemes are located in agricultural areas, special attention was given to specifying layouts for civil structures in a manner that would obviate the need to permanently destroy any productive agricultural land. For example, in canal drop schemes that utilize by-passes, the revised designs incorporate closed conduits for this reason. Similarly for the dam based schemes, the revised designs represent a marked improvement over the original ones because major new civil works to create water intake and conveyance structures such as tunnels have been eliminated. Furthermore, none of the schemes will lead to the resettlement of communities or the displacement of existing farms. In each case, special care was taken to ensure that the water conveyance structures as well as the grid-tie arrangements would make maximum use of existing rights-of way for the states.

*Cost Estimation Procedure*

19. Using information on 1990 proforma (budgetary) price quotations for equipment and materials that were made available by the SEBs as well as by international and local manufacturers and suppliers, the base costs of the main components of each scheme were computed. Total capital costs were estimated by increasing the base costs to incorporate: (i) the installation costs of the main items of equipment; (ii) physical contingencies; (iii) price contingencies to reflect inflation; and (iv) taxes and duties. Because of the detail provided in the standardized specifications for equipment and instrumentation, and the use of a minimum of civil works to establish the schemes, physical contingencies were calculated to be 5% of base costs. Price contingencies were derived assuming that the annual inflation rate (local costs) would vary from 8.4% in 1991, 7.0% during 1992-93, and decline to 6.6% by 1994. It also was assumed that taxes on the main cost items would be levied at 3% for civil works, 6% for electro-mechanical equipment, and 3% for electrical systems. More detailed and site specific development plans, including implementation schedules which dovetail with the irrigation system operating plans, would need to be prepared before more elaborate disbursement profiles for each state can be prepared. 2/

## G. Evaluation of Schemes

*Economic Evaluation of Schemes*

20. For economic analysis, a distinction was made between costs expressed in economic terms and those expressed in financial terms. In line with World Bank practice for economic analysis on India, the domestic component of the capital costs for equipment and civil works were

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2/ The estimates of the base costs of the main components of each scheme, especially the electro-mechanical equipment, and the assumptions about the annual rate of inflation and price contingencies need to be revised due to the GOI decision in July, 1991 to adjust the exchange rate for the Rupee to a level of about Rs. 25 per US Dollar. During the period of the ESMAP study, the exchange rate was in the range between Rs. 17.5-18.5 per US Dollar.

adjusted by applying a standard conversion factor of 0.8, and removing taxes and duties. Annual operating and maintenance costs were taken to be equivalent to 2% of capital costs over the 25 year economic life of each scheme. The economic value of the energy benefits would be Rs. 0.80/kWh; it is expected that during detailed design of the proposed India Renewable Energy Development Project, a more comprehensive assessment of the benefits would be made to incorporate capacity credits at a justified level.

*Cost Recovery Requirements For SEBs.*

21. One of the goals for the follow-up to this study is to demonstrate that, despite the persisting financial problems of the SEBs, the schemes in each state could be executed and managed by SEBs in a manner that would ensure economic cost recovery. During the study, discussions were held with senior officials at the state level to define a suitable framework for involving the SEBs in the implementation the mini-hydro schemes. The discussions centered primarily on the need to streamline project management arrangements in each state, and to introduce an effective system for monitoring and controlling the cost-effectiveness of mini-hydro schemes; the overall aim, despite the persisting financial problems of the SEBs, was to ensure that the mini-hydro programs in each state would be managed by SEBs in a manner that would ensure economic cost recovery. The consensus reached was that it would be feasible to set up mini-hydro "cost centers" in the respective SEBs to record, control, and monitor all costs associated with the mini-hydro program, and to track progress in constructing and operating the schemes to achieve economic cost recovery and self-sufficiency. Accordingly, one objective for the financial analyses was to determine the "profitability" of the proposed SEB mini-hydro *"cost centers"*.

**ECONOMIC EVALUATION OF DAM BASED MINI-HYDRO SCHEMES**

| SCHEME NAME | INVESTMENT (Rs./kW) | ENERGY PROD. (kWh pa/100 Rs.) | EIRR (%) | NPV @12% (Rs.million) |
|---|---|---|---|---|
| KARNATAKA | | | | |
| Brindavan | 5592 | 117.5 | 65.7 | 428.7 |
| Harangi | 5942 | 51.8 | 30.8 | 103.0 |
| Kabini | 10972 | 29.8 | 17.5 | 57.8 |
| Nugu | 8827 | 32.2 | 19.1 | 50.0 |
| Deverebelerkere | 5204 | 58.9 | 42.1 | 61.0 |
| Mudhol | 8915 | 58.3 | 34.5 | 33.2 |
| Malaprabha | 8228 | 44.2 | 26.3 | 50.4 |
| TAMIL NADU | | | | |
| Lower Bhavani | 5891 | 58.3 | 34.6 | 172.6 |
| Thirumurthy | 9602 | 45.9 | 30.4 | 64.4 |
| Amaravathy | 8482 | 46.1 | 27.4 | 75.3 |
| Aliyar | 11642 | 61.6 | 38.5 | 57.7 |
| Sathanur | 5362 | 75.7 | 44.0 | 136.9 |
| Peechiparai | 11724 | 33.2 | 19.7 | 43.9 |
| Perunchani | 12962 | 26.5 | 21.3 | 39.0 |
| ANDRA PRADESH | | | | |
| Lower Manair | 9297 | 71.3 | 41.4 | 136.5 |
| KERALA | | | | |
| Peechi | 7836 | 73.2 | 41.2 | 210.0 |
| Mangalam | 14140 | 20.4 | 13.5 | 10.6 |
| Kuttiyadi | 9130 | 55.7 | 40.7 | 199.5 |
| Maniyar | 5426 | 71.4 | 41.1 | 394.9 |

SOURCE: ESMAP estimates

Table 1

**ECONOMIC EVALUATION OF MINI-HYDRO SCHEMES AT CANAL DROPS AND WEIRS**

| SCHEME NAME | INVESTMENT (Rs./kW) | ENERGY PROD. (kWh pa/100 Rs.) | EIRR (%) | NPV @12% (Rs.million) |
|---|---|---|---|---|
| ANDHRA PRADESH | | | | |
| Guntur BC Cluster | 12395 | 44.3 | 22.9 | 429.8 |
| Adanki BC Cluster | 12891 | 21.3 | 14.2 | 119.4 |
| Lock-In-Sula | 9807 | 56.0 | 29.2 | 97.0 |
| PUNJAB | | | | |
| Bhatinda BC Cluster | 14702 | 38.5 | 20.4 | 91.5 |
| Kotla BC Cluster | 19478 | 27.9 | 14.7 | 222.1 |
| Abohar BC Cluster | 17396 | 29.6 | 18.6 | 305.2 |
| Bhakra Cluster | 14406 | 51.0 | 19.7 | 368.5 |
| KARNATAKA | | | | |
| Shahpur BC Cluster | 16981 | 21.6 | 13.3 | 206.8 |
| Attehala Weir | 22560 | 28.6 | 12.2 | 22.7 |
| Maddur (MBC 1) | 10089 | 44.4 | 29.1 | 67.8 |
| Kilara (MBC 2) | 16199 | 26.5 | 13.9 | 55.2 |
| Anveri | 10245 | 42.8 | 29.3 | 44.0 |
| Rajankollur | 9848 | 30.3 | 20.3 | 49.8 |

SOURCE: ESMAP estimates

Table 2

22. The minimum cashflow requirements of the SEB mini-hydro *"cost centers"* were computed based on full recovery of costs incurred due to debt servicing plus the annual operation and maintenance of schemes (i.e., estimated to be 2% of capital cost per annum). Since the goal is to achieve economic cost recovery, it was assumed that revenues would accrue to the mini-hydro *"cost centers"* from the "sale" of energy to the grid; as such the financial value of the revenue generated by the mini-hydro "cost center" was established in terms of: (i) the tariff paid for bulk power imports into each state (i.e., from the National Thermal Power Corporation); and (ii) the average tariff for power sales from the grid in each state.

**CASHFLOW BALANCE FOR MINI-HYDRO "COST CENTERS"**

| STATE | TOTAL CAPACITY (MW) | ENERGY OUTPUT (GWh/yr.) | WEIGHTED AV. COST (Rs./kWh) | AVERAGE TARIFF (Rs./kWh) | NET REVENUES FOR "COST CENTERS" (Rs. millions p.a) |
|---|---|---|---|---|---|
| Andhra Pradesh | 19.5 | 95.3 | 0.49 | 0.62 | 10.5-12.4 |
| Kerala | 26.6 | 120.0 | 0.29 | 0.53 | 28.8-37.4 |
| Karnataka | 37.7 | 170.0 | 0.44 | 0.73 | 27.3-49.4 |
| Tamil Nadu | 24.8 | 81.5 | 0.39 | 0.87 | 17.1-39.1 |
| Punjab | 22.2 | 133.0 | 0.51 | 0.67 | 12.0-21.4 |

Source:ESMAP estimates; SEBs and KPC.

Table 3

24. Based on the minimum cashflow calculations, it was determined that the weighted average costs of generation for the "cost centers" in the southern states would vary from Rs.0.29/kWh in Kerala to 0.49/kWh in Andhra Pradesh (Table 3). Similarly in Punjab State, the weighted average cost of generation for the mini-hydro "cost center" was estimated to be Rs. 0.51/kWh. At present, the tariff for NTPC bulk power supply into the state grids in the southern region is Rs. 0.60/kWh. With the exception of Kerala, which is entirely dependent on hydropower, the average tariff for sales in the southern region is higher than the rate paid for NTPC supply. The average tariff for sales is Rs. 0.53/kWh for Kerala, and varies from Rs. 0.62-0.87/kWh in the other three states; for Punjab, the average tariff is Rs.0.67/kWh. Hence the net revenues in excess of minimum cashflow requirements would be positive for the mini-hydro "cost centers" in each state, indicating that the mini-hydro "cost centers" would be self-supporting (Table 3).

*Return on Equity for Private Sector Schemes*

25. Because the SEBs have limited resources available to accelerate the development of irrigation based mini-hydro schemes, the State governments have taken steps to encourage private sector participation in the development of the prospects; new guidelines and regulations have recently been issued to foster private sector participation in mini-hydro development as an alternative source of captive generation; in response, several private companies have expressed an interest in developing the schemes to improve the reliability of power supply to their associated industrial plants. The Karnataka State Government, for example, has approved leases for private development of several prospective mini-hydro sites including the canal drop scheme at Maddur, and the dam based scheme at Mudhol, both of which are covered in this report. Accordingly, a sample evaluation was made to determine the financial rate of return on equity that would be realized by the prospective private investors, based on the conditions stipulated in lease agreements in Karnataka. It has been assumed that the private companies would obtain up to 50% of the investment required in the form of loans from the Indian Renewable Energy Development Agency (IREDA) which currently would be available at an interest rate of 12.5% p.a with 10 years maturity.

26. With the conditions of the lease agreements in Karnataka, and assuming that designs presented in this study are adopted, the cost of generation at the Maddur canal drop would be Rs.0.73/kWh and at Mudhol, Rs.0.61/kWh. The installed capacity of the irrigation based mini-hydro schemes will not be available at all times during the year; accordingly, the financial savings were confined to the variable costs of industrial diesel auto-generation (Rs. 1.16/kWh). Taking into account the annual generation of each scheme, the deductions that would be allowed for depreciation (i.e., assuming 20 year straight line depreciation), wheeling charges to be levied by the Karnataka Electricity Board (KEB), but not the payments to be made to the State in lieu of electricity duties and the levies for maintenance of the irrigation reservoirs, the return on equity contributed by the private companies to develop each scheme would be 45% for the Maddur scheme, and 75% for the Mudhol scheme. *Prima facie* it would seem that development of the two schemes would be an attractive investment for private companies which need to secure a non-diesel source of captive power; private companies, especially those that plan to acquire diesel generators, would be in a position to pay royalty charges to gain access to the use of regulated water flows from irrigation reservoirs such as has already been proposed in Karnataka.

### H. Proposed Mini-Hydro Demonstration Program

27. All the twelve schemes in Punjab State are earmarked for development by the PSEB using World Bank/IDA financing for the mini-hydro component of the ongoing Punjab Irrigation and Drainage Project. The schemes in the southern region are to be developed as part of the mini-hydro demonstration component of the proposed India Renewable Energy Development Project. Under the proposed project, the World Bank is to provide financing to the GOI to establish a funding facility for mini-hydro development. It is envisaged that SEBs as well as private sector companies would be eligible for loans from the facility to develop the irrigation based mini-hydro prospects. Subject to the detailed preparation and appraisal of the proposed project, it is expected that the World Bank would provide technical assistance to address the following requirements for effective implementation of the schemes:

(a) strengthening the capacity of IREDA to administer the funding facility in a manner that would accelerate the development of economically and financially viable mini-hydro schemes based on design principles and approach presented in this report. If feasible, a separate revolving fund would also be established at IREDA for pre-investment work needed to sustain the pipeline of viable mini-hydro projects;

(b) conducting in-service training programs under DNES/IREDA sponsorship to develop the capability of professional personnel (i.e., from SEBs, private sector, etc.) involved in planning and executing irrigation based mini-hydro schemes, especially the investigation, design, construction, operation, and maintenance of grid-tied schemes;

(c) strengthening the capacity of DNES to promote and support a nationwide effort to improve planning and policy formulation for mini-hydro development, and to accelerate the investigation and preparation of prefeasibility studies for prospective mini-hydro schemes associated with existing and planned irrigation dams and canal systems in all states.

(d) strengthening the capacity of the SEBs to implement the mini-hydro programs, especially on technical matters such as identifying, investigating, and preparing preliminary designs for mini-hydro prospects, and on project management involving the application of "cost centers" and project matrix arrangements to implement the schemes (e.g., supervising procurement and construction work, etc.).

28. During the study, discussions were held with senior officials at the Central and State GOI levels and the SEBs to define a suitable framework to minimize implementation delays. The consensus reached was that the following arrangement may be needed to strengthen the capacity at the state level to accelerate irrigation based mini-hydro programs during the Eighth Plan. Further work is required to resolve the issues below, taking into account the particular organizational settings in each state, and more in-depth World Bank appraisal of the proposed project.

29. *Inter-Agency Coordination at State Government Level.* The key agencies for developing irrigation based mini-hydro schemes are the SEBs and the Irrigation Departments. Currently, coordination between the two agencies on matters concerning investigation, design, construction, and operation of schemes usually is ad-hoc. There is consensus on the need to formalize such coordination by establishing Mini-Hydro Coordination Committees in each state. It is envisaged that such Committees, working under the chairmanship of the Secretary, Department of Power and/or

Energy in the respective state governments, would meet at least once every six months to review progress, especially to resolve any issues and bottlenecks that may arise in the mini-hydro program, especially in arranging for all the necessary approvals of proposals that would be submitted by both public and private sector organizations for the design and construction phases of each scheme. These arrangements need to be formalized before the implementation of the schemes gets underway for the proposed project.

30. *Establishment of Mini-Hydro Cells in SEBs.* At present, there are no clear lines of accountability within the SEBs for the functions associated with mini-hydro development. Typically, the technical staff involved in the design, construction, and operation/maintenance phases of the mini-hydro are scattered in several departments within the SEBs. For the most part, persons designated as Project Managers for mini-hydro schemes have no direct administrative control over the staff involved in the design and implementation functions. In anticipation of an expanded mini-hydro program during the Eighth Plan, some steps have already been taken to improve coordination among the SEB technical staff; the approach has been to establish Mini-Hydro Cells or Divisions under the supervision of a Chief Engineer. For example, the PSEB already has established a Mini-Hydro Division under the supervision of the Chief Engineer (Mukerian Project); and the TNEB maintains a Mini-Hydro Cell under the supervision of the Chief Engineer (Civil Designs). On the other hand, the KPC has adopted the project matrix approach under which the Chief Engineer (Planning and Renewable Energy) takes charge of all aspects of the mini-hydro program, drawing as necessary on personnel from other departments. The roles and responsibilities of the Mini-Hydro Cells or Divisions need to be further elaborated, especially if the role of each SEB eventually becomes one of a State Nodal Agency to which the Committees could delegate some statutory tasks, such as securing formal clearances for the schemes from agencies responsible for regulatory matters concerning forestry and environmental protection, etc.

## I. Conclusions

31. The study provides a systematic framework for designing economically viable mini-hydro schemes using the country's extensive infrastructure for surface irrigation. The mini-hydro component of the proposed India Renewable Energy Development Project is intended to translate the results of this study into a viable and cost-effective approach to develop the mini-hydro potential that is associated with the country's vast network of surface irrigation infrastructure, and to increase the contribution of such low cost and environmentally benign schemes to the overall strategy to reduce power supply deficits and improve service quality in outlying parts of the grid. The next steps are to proceed to prepare detailed designs, cost estimates, technical specifications for procurement purposes, and implementation plans for the mini-hydro schemes in each of the states covered by this study, and to systematically identify and develop similar schemes in the remaining states of the country.

# I. INTRODUCTION

## A. Background

1.1 In India, there is the general perception that mini-hydro schemes are economically unattractive investments which must be assigned a lower priority relative to the large conventional hydropower systems. Over the past decade, the pace of India's large conventional hydropower program has slowed down because of: (i) the lack of financial resources in the states with the greatest hydropower potential; (ii) the recurring and drawn out disputes over water rights between states; and (iii) environmental and resettlement issues associated with large schemes; and (iv) the limited technical resources to proceed simultaneously with the preparation of several large schemes. Recognizing that the above impediments do not usually arise with mini-hydro schemes, the GOI is re-evaluating the scope for increasing the contribution of mini-hydro schemes to the power development goals of the Eighth Plan. 2/

1.2 In a recently completed review of the country's non-conventional energy program, the Energy Sector Management Assistance Program (ESMAP) concluded that all the basic prerequisites for economically viable mini-hydropower generation exists at sites in India that are associated with irrigation water storage and distribution infrastructure (i.e., to harness the hydraulic energy created by the discharge of water from irrigation dams, and across diversion weirs, and canal drops). 3/

1.3 Since independence in 1947, the total area under irrigation in the country has increased from 19.5 million hectares to over 70 million hectares. In the mid-1980s, the Rural Electrification Corporation (REC) conducted a survey to obtain data and information on the potential for power generation on existing irrigation systems in the country. The information supplied by the State Electricity Boards (SEBs) indicated that about eight hundred sites associated with surface irrigation structures in eight states were among the most prospective sites for mini-hydropower development (*Table 1.1*).

**IRRIGATION BASED MINI-HYDRO PROSPECTS IN SELECTED STATES**

| STATE | NO. OF SITES IDENTIFIED | ESTIMATED CAPACITY (MW) |
|---|---|---|
| Andhra Pradesh | 283 | 112 |
| Karnataka | 197 | 159 |
| Tamil Nadu | 33 | 115 |
| Maharastra | 114 | 69 |
| Uttar Pradesh | 62 | 153 |
| Punjab | 44 | 79 |
| Bihar | 38 | 34 |
| West Bengal | 23 | 57 |
| | 794 | 778 |

Source: REC, CEA, DNES.

Table 1.1

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2/ India's hydropower potential is equivalent to about 100,000 MW of which only 5000 MW is associated with mini-hydro sites. Only 16,000 MW have been developed; some 47,000 MW are under construction, and a further 23,000 MW are at various stages of planning.

3/ In November, 1988, ESMAP issued a report: "India: Opportunities for Commercialization of Non-Conventional Energy Systems".

1.4 Despite the initial assessment by ESMAP, there still are doubts within the GOI about the economic viability of irrigation based mini-hydro schemes. These doubts persist because of recent experience with the construction of pilot irrigation based mini-hydro schemes in the country. During the Seventh Plan, the SEBs in the south initiated construction work on sixteen schemes (*Table 1.2*); as of September, 1990, only six of those schemes had been commissioned. In cost effectiveness terms, the schemes developed in Kerala were the most competitive (Rs. 14,000-19,000/kW); altogether, about Rs. 260 million was spent to develop three irrigation based mini-hydro schemes. In Andhra Pradesh, the pilot program concentrated on mini-hydro prospects on the Kakatiya D83 Branch Canal. Work was initiated on six canal drop schemes, three of which already have been commissioned; as indicated in the table below, the expenditure on the schemes have been in the range of Rs.19000 to 28,000 per kW installed. The least cost effective schemes were in Karnataka. About Rs. 317 million was invested to develop four schemes with a total capacity of about 11 MW; the expenditure on three of the four schemes exceeded Rs. 48,000/kW installed.

**ESTIMATED COSTS OF PILOT SCHEMES IN SOUTHERN REGION**

| STATE/SCHEME | CAPACITY (kW) | INVESTMENT a/ (Rs. mil.) | (Rs./Kw) |
|---|---|---|---|
| ANDHRA PRADESH | | | |
| Kakatiya BC | ( 3*220 | 12.5 | 18939 |
| Cluster 1 | ( 3*220 | 13.1 | 19848 |
| | ( 3*220 | 14.4 | 21818 |
| Kakatiya BC | ( 3*500 | 23.0 | 23000 |
| Cluster 2 | ( 3*500 | 24.6 | 24600 |
| | ( 3*500 | 24.1 | 24100 |
| KARNATAKA | | | |
| Sirwar | 1*1000 | 49.6 | 49600 |
| Kalmala | 1*400 | 34.0 | 85000 |
| Ganekal | 1*350 | 17.3 | 49429 |
| Mallurpur | 2*4500 | 216.6 | 24067 |
| KERALA | | | |
| Peppara | 1*3000 | 56.7 | 18900 |
| Madupatti | 1*2000 | 33.2 | 16600 |
| Chimoni | 1*2500 | 36.0 | 14400 |
| TAMIL NADU | | | |
| Lower Bhavani(LBC) | 4*2000 | 207.5 | 25938 |
| Vaigai | 2*3000 | 140.1 | 23350 |
| Pykara | 1*2000 | 69.1 | 34550 |

a/ all estimates in 1988 prices.

Source: APSEB, KSEB, PSEB, TNEB, KPC.

Table 1.2

1.5 The cost of developing irrigation based mini-hydro schemes in other regions of the country have also been high. For example, the Punjab State Electricity Board (PSEB) recently commissioned four schemes which are located on canal drops located at Nidampur, Rohti, Tuhi, and Daudar on the Sirhind Canal (*Map - IBRD 22785*). The average expenditure for the schemes, which have a combined capacity of about 4 MW, 4/ was about Rs. 30,000/kW installed.

1.6 The private sector has been invited to participate in developing irrigation based mini-hydro schemes; the performance so far also has been poor. In Karnataka, the State government initially offered leases to allow private companies to develop six prospective sites. Six private companies signed leases to develop one or more sites; only one was able to mobilize the resources required to begin construction at the site. Eventually, the leases for the remaining sites lapsed. The Karnataka Power Company (KPC) took over responsibility for the development of two of those sites.

*Improving Cost-Effectiveness*

1.7 Following the transfer of responsibility of mini-hydro schemes (up to 3 MW capacity) from the Department of Power (DOP) to the DNES, a multi-agency Sub-Committee on Mini-Hydropower was convened under the auspices of the DNES Working Group for the Eighth Plan to formulate a strategy to improve the cost-effectiveness of mini-hydro programs in general, and to review proposals for the Eight Five-Year Plan (1990-95). In parallel with the work of the Sub-Committee, the GOI through DNES requested ESMAP to assist further in critically evaluating proposals for new irrigation based mini-hydro schemes in several states, and if warranted by the findings, to address comprehensively the pre-investment requirements for a multi-scheme investment program for consideration by international and/or domestic financial institutions.

1.8 Following the request for ESMAP assistance, a preliminary but critical examination was made of available information and documentation on the existing and proposed schemes. As a result, ESMAP identified three main shortcomings in the approach to irrigation based mini-hydro development in the country. First, the initial batch of schemes were conceived, designed, and executed as scaled down versions of large conventional hydro installations. Consequently, there are numerous redundancies in the designs for key features such as the layout of civil works, the facilities incorporated into the powerhouse structures, the selection of turbine-generator equipment, and the specification of electrical switching and protection systems. Second, due to the use of relatively complex layouts for the schemes, the gestation time to construct and commission the schemes has been unacceptably high. For example, it has taken over four years to complete the majority of the pilot schemes in the southern region. As a result of the slow pace of implementing the construction work, there has been a significant escalation in capital costs and in interest payments during construction. 5/ Third, the viability of the pilot schemes were being undermined by the use of unnecessarily large numbers of technical staff to operate and maintain the mini-hydro schemes. The

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4/ The schemes were developed as part of a pilot program that was funded exclusively by the State Government in Punjab.

5/ In Tamil Nadu, such delays resulted in marked increases in the costs of establishing all three pilot schemes. Over the five years that it took to develop the schemes: the costs of the Lower Bhavani scheme increased from Rs. 207 million to Rs. 241 million; the costs of the Vaigai scheme also increased from Rs. 140 million to Rs. 162 million; and that for the Pykara scheme, from Rs. 70 million to Rs. 82 million.

GOI concurred with the preliminary findings of ESMAP; consequently ESMAP proceeded with the Pre-investment study.

## B. Objectives

1.9 The principal objective of this study was to apply techno-economic criteria to improve the design and economic viability of irrigation based mini-hydro schemes, and to identify and prepare a medium term investment program to develop a series of irrigation based mini-hydro schemes in the southern region of India. Accordingly, the study covered previously identified and investigated sites in the States of Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu which have similar topography and irrigation regimes. At the request of the DNES, the scope of the study was expanded to include twelve prospective sites in the State of Punjab, all of which are earmarked for development under the mini-hydro component of the ongoing World Bank/IDA financed Punjab Irrigation and Drainage Project.

1.10 The pre-investment study was structured to:

(a) assess the technical and economic feasibility of developing between 10 to 20 prospects in each state, especially those that had already been investigated to at least the feasibility stage by the respective SEBs;

(b) critically evaluate the cost-effectiveness of engineering designs and specifications that had been proposed by the SEBs, and to redesign each scheme to maximize the number of kilowatt hours produced annually per unit of investment. Also the aim was to determine the minimum infrastructure and equipment required to establish each scheme;

(c) update and revise the estimates of the capital costs of developing the schemes, to evaluate the economic and financial viability of establishing the schemes to provide energy and voltage support to the power grid in the respective states;

(d) explore the scope for achieving full cost recovery on all phases of mini-hydro development; and

(e) evaluate the financial returns that private companies and investors would realize by developing the schemes as alternative sources of captive generation;

(f) prepare a comprehensive report which would define technical concepts and design methodology used for the study, the relative benefits and costs of the proposed program, investment requirements at the state level, and the financial impact of the proposed program on the states.

1.11 Despite the focus on the southern region, the design methodology was also meant to be applicable to the preparation of similar investment programs in the other regions of the country.

## C. Conduct of Pre-Investment Study

1.12 The fieldwork was conducted in three phases in collaboration with counterparts from the DNES, the SEBs, and KPC. The preliminary evaluation of SEB proposals was done from September to December, 1989. 6/ The second phase began in January, 1990; members of the ESMAP team visited all five states to collect and review site specific data and SEB proposals for each scheme to verify irrigation discharge data with irrigation authorities, and to inspect the prospective mini-hydro sites. Photographs of the sites are presented in the Technical supplement. After verifying the accuracy of pertinent data to establish key design parameters, each of the SEB proposals was critically examined, and compared to alternative layouts and turbine-generator configurations. Also during the second phase, ESMAP consultants held preliminary discussions with senior managers of the SEBs to identify and review issues concerning the suitability of the present organizational set up in the SEBs for the implementation phase. 7/

1.13 The second phase concluded in May, 1990 when the methodology for design and evaluation of schemes, and the preliminary results of the fieldwork, were reviewed with counterparts from the SEBs at a "Project Identification Workshop" in Bangalore, Karnataka.

1.14 The third phase began in June, 1990 and ended in December, 1990. The main goals were to:

(a) update the capital cost estimates for each scheme based on revised designs for civil structures, electro-mechanical equipment, electrical protection and control systems, and the grid-tie arrangement;

(b) re-evaluate the economics of the prospective schemes which take into account their role in providing energy and voltage support to remote parts of the grids in districts of the respective states;

(c) evaluate the financial impact of the schemes on each state. Specifically, the aim was to establish minimum cashflow requirements to ensure full cost recovery on mini-hydro programs by the SEBs, and to assess the "profitability" of mini-hydro "cost centers" in each state; and

(d) evaluate the financial attractiveness of the schemes to private sector companies. Given the conditions stipulated in recent approved lease agreements in the southern states, the aim was to determine the rate of return on equity for private sector companies which elect to develop captive power plants at some of the prospective sites.

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6/ The findings were presented in the "Working Paper on Project Identification", issued by ESMAP in December, 1989.

7/ A draft working paper was prepared, entitled "The Institutional and Operational Aspects of Irrigation and Canal Based Mini-Hydropower Development", dated May 1990.

## D. Counterparts For Study

1.15 The principal counterpart agency for the GOI on this study is the DNES. Other concerned agencies at the central GOI level includes the Central Electricity Authority (CEA) which has the technical clearance responsibility for all power supply schemes that require an investment of Rs. 50 million or more. At the state level, the designated counterparts to ESMAP were: (a) the State Electricity Boards (SEBs) in Andhra Pradesh, Kerala, Tamil Nadu, and Punjab respectively; and (b) the Karnataka Power Company (KPC). Other central and state GOI agencies which were consulted during the study include the Irrigation Departments in the respective states, the Rural Electricity Corporation (REC), the Power Finance Corporation (PFC), and the Alternate Hydro Electricity Center (AHEC). Officials of the GOI Department of Economic Affairs (DEA) and the DOP were regularly briefed on the progress of the study.

## E. Prospects Studied

*Prospects In The South*

1.16 The States of Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu extend across the southern cone of the Indian Peninsula. These states are drained by the Godavari river to the north, the Krishna river in the central zone, and the Cauvery river to the south. The three major rivers rise in the high plateau areas of the Western Ghats, and flow eastward across the Deccan Plateau before discharging into the Bay of Bengal; they are the primary sources of water for an extensive network of irrigation schemes. Prior to independence, several major irrigation dams were constructed on the Cauvery river in both Karnataka and Tamil Nadu, including the Krishna Raja Sagar (KRS) and Mettur schemes respectively. A few other large irrigation dams were constructed on the main tributaries of the Godavari (i.e., Nizamsagar) and Krishna ( i.e., Tungabhadra) Rivers. Since independence, large new irrigation dams have been constructed on all the three major river systems, including the Sri Rama Sagar on the Godavari River, the Nagar Junar Sagar and Upper Krishna systems on the Krishna River, and the Hemavathy in the Cauvery River basin. Moreover, a wide range of smaller dams and diversion structures and canals have been built to extend the irrigation network throughout the southern region.

1.17 The potential for power generation on irrigation dams, diversion weirs, and canals in the southern states is particularly good because of three factors. First, the terrain is undulating, hence numerous drops exist along the irrigation canals and diversion weirs in the region; such drops provide sufficient hydraulic heads for low-head (i.e., 3-15 meters) mini-hydro applications. Second, because of the relatively large number of irrigation storage reservoirs in the region, the hydraulic head that is created when water is discharged through sluices in irrigation dams into the canals is also suitable for power generation. Third, the irrigation season in the southern states extends from July through March. Therefore for about nine months each year, a fairly continuous supply of irrigation water is available for power generation. 8/

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8/ Recent efforts in the region to promote integrated water management practices have improved the regulation of waterflows in the main canals; therefore this practice has enhanced the scope for applying simple standard turbine-generator equipment to develop mini-hydropower schemes with high plant load factors.

1.18 *Andhra Pradesh.* The Andhra Pradesh State Electricity Board (APSEB) has identified a total of 286 prospective mini-hydro sites on the existing network of canals: (i) 165 are located at canal drops on the Sri Rama Sagar scheme on the Godavari River; and (ii) 106 canal drops on the Nagarjunar Sagar scheme on the Krishna River. Among the more promising sites are those located in a cluster along the D83 branch of the Kakatiya Canal, and on the Lower Manair Reservoir which also is linked to the Kakatiya Canal. The main prospects on the Nagarjuna Sagar (NSR) scheme are located on the Adanki, Guntur, and Ongole Branch Canals. There are a only few dam based prospects in the state, including the Lower Manair reservoir which is covered by this study. The APSEB collaborated with ESMAP to review proposals on about 20 prospects (*Map - IBRD 22783*). These consist of canal drops on the Guntur, Adanki, Ongole, and Kakatiya D-83 Branch Canals, the Lock-In-Sula Regulator of Kurnool Canal, and the Lower Mannair Reservoir. Altogether, the prospects that are covered in this study have a total annual power generation potential of the order of 150 GWh.

1.19 *Karnataka.* The Karnataka Power Company (KPC) 9/ has completed investigations and pre-feasibility studies on mini-hydro prospects associated with irrigation dams at Brindavan, Kabini, Nugu, and Harangi in the Cauvery river basin, 10/ and Mudhol, Malaprabha, and Devrebelerkere 11/ in the Krishna river basin. Also, the KPC has completed investigations for over ten canal drop prospects along: (i) the Left Bank Canal on the Tungabhadra scheme which draws water from a major tributary of the Krishna river; (ii) the Visveswaraiah Canal which draws water from the KRS reservoir (i.e., the Brindavan Dam) on the Cauvery river; and (iii) the Shahpur Branch Canal which distributes water from the Narayanapur Reservoir on the Upper Krishna scheme. Altogether, the KPC collaborated with ESMAP to review proposals on seven dam based prospects, one prospect at the Attehala diversion weir, and five canal drop prospects, including a cluster comprising six drops on the Shahpur BC (*Map - IBRD 22784*). The prospects covered in this study have a total annual power generation potential of the order of 140 GWh. This estimate excludes the potential yield of the Tungabhadra LB Canal which already is under development by the KPC.

1.20 *Tamil Nadu.* In Tamil Nadu, several of the major irrigation schemes draw water from three rivers: the Cauvery river in the central zone; the Ponniar river in the north; and the Vaigai river which is adjacent to the Cauvery river. The Tamil Nadu Electricity Board (TNEB) has completed investigations and pre-feasibility studies for mini-hydro prospects at irrigation dams at Lower Bhavani, Amaravarthy, Thirmurthy, Sathanur, Peechiparai, Perunchani, and Aliyar. Also, schemes have recently been commissioned on three dams (Lower Bhavani, Pykara, and Vaigai). Although the TNEB also has investigated the mini-hydropower potential of several major irrigation canal systems in the state, the power potential of the canal systems combined is limited to about 6 MW. There are some 26 drops on the Cauvery Canal, 40 drops on the Periyar Canal, and over 60 drops on the Parambikulam Canal. The present thrust of the TNEB is to develop the dam based

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9/ In Karnataka, the lead agency for developing the mini-hydro schemes is the KPC. The Karnataka Electricity Board (KEB), which is responsible for the state grid, purchases power in bulk from the KPC.

10/ Investigations are near completion on the Hemavathi and Yagachi dams in the Cauvery River Basin.

11/ The Devrebelerkere Irrigation Tank is located on a tributary of the Tungabhadra river in the Upper Khrisna River Basin.

schemes. The TNEB provided ESMAP with information and data for mini-hydro prospects associated with eight irrigation dams (*Map - IBRD 22781*) which when developed, would contribute about 130 GWh annually to the state grid. In addition, preliminary designs were developed for 5 canal drop prospects located on the Grand Anicut, Tongkorai, Tughlapatti, Villampati, and Mettur West Bank canals, respectively.

1.21 *Kerala.* Compared to the other three states in the south of India, irrigation dam and canal systems in Kerala are not as extensive. The main prospects for irrigation based mini-hydro development are associated with the numerous diversion weirs and barrages that have been installed for irrigation and water supply purposes. 12/ The Kerala State Electricity Board (KSEB) has completed feasibility studies on the most promising prospects, including those associated with the Peechi Irrigation Dam, the Maniyar Barrage of the Pamba Irrigation project, 13/ the tailrace of the Kuttiyadi Dam which discharges water into the Peuvannunmuzhy Irrigation Reservoir, and the Mangalam dam (*Map - IBRD 22782*). The KSEB collaborated with ESMAP to review proposals on the above schemes which would yield about 120 GWh annually.

*Mini-Hydro Prospects in Punjab State*

1.22 The state of Punjab is located on the Indo-Gangetic Plains which has a much more gently graded topography than exists in the south. Over the past hundred years, an extensive network of irrigation canals has been developed in the state; water is diverted from three international rivers (the Ravi, Beas, and the Sutlej) which flow from northwestern India into Pakistan. There is considerable potential for power generation at numerous canal drops (*Map - IBRD 22785*). Since the available heads at the majority of canal drops is less than five (5) meters, power generation is feasible only because of the relatively large flows which are available in the canals for over ten months each year.

1.23 In 1982, the Punjab Department of Irrigation and Power surveyed over 150 canal drops in the state and concluded that 110 MW could be harnessed from mini-hydro schemes. The Punjab State Electricity Board (PSEB) has since earmarked several prospects for development along: (i) the Sirhind Canal network which has 63 drops with a power generation potential of 43 MW; and (ii) the Bhakra Main Line Canal 14/ which has 34 drops and a power potential of 55

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12/ Kerala has completed preliminary investigations for over 150 river bed schemes which require the construction of small diversion weirs, 25 of which have been studied to the feasibility level. As part of the study, ESMAP prepared preliminary designs for sites at Chembukkadavu, Passukkadavu, and Wanchiam.

13/ The Kerala State Government plans to construct two additional barrages on the Kakkad river at Allunakal and Karikkayam to increase water supply to the Pamba Project. The proposed expansion would lead to the eventual development of a cascade of mini-hydro schemes at Maniyar, Allunkal, and Karikkayam on the Kakkad River which would eventually yield a total of 28 MW and 110 GWh/yr.

14/ Also referred to as the Nangal Hydel Canal.

MW. The PSEB also is proceeding to develop the considerably larger power generation potential that has been identified in the Upper Bari Doab Canal (UBDC). 15/ The primary focus of this study is on the twelve prospective mini-hydro sites that have been identified on the Sirhind Canal network, plus two others on the Bhakra Main Line Canal, all of which are earmarked for development under the ongoing Punjab Irrigation and Drainage Project.

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15/ The PSEB estimates that over 210 MW of power can eventually be harnessed from a special channel that has been constructed between the Madhopur Headworks and a cross regulator at Tibri on the UBDC. The prospects are being developed in four stages: three units of 15 MW each was installed during stage I; an additional three units of 15.45 MW are currently being installed under stage II; three units of 23 MW each are to be installed under stage III; and for stage IV, three units of 16.5 MW would be installed.

## II. CONCEPTUAL DESIGN AND STANDARDIZATION

### A. Overview

2.1 The primary design objective for irrigation based mini-hydro schemes is to maximize the number of kilowatt hours produced annually per unit of investment or the *annual energy productivity* at each site without disrupting irrigation operations. The robustness of the sizing procedure (i.e., to maximize *annual energy productivity* was checked against the more elaborate analysis which calculated the B/C ratios for the incremental generation by each additional unit for prospective dam based schemes. The analysis confirmed that the *annual energy productivity criteria* provides a reliable and consistent basis for selecting the optimal the plant size.

2.2 An iterative procedure was used to select and evaluate the techno-economic feasibility of installing different configurations of multi-unit turbine-generators. ESMAP collaborate with SEB counterparts to improve the cost-effectiveness of original designs, thereby enhancing economic attractiveness, as described below:

(a) *Flowchart I* - to obtain and verify the accuracy of all available data and information on the physical characteristics and irrigation discharges at the prospective sites. This required a considerable amount of fieldwork, including an inspection of each site to verify key design parameters, to develop a conceptual design of the alternative layouts that can be adopted for the scheme, and to convert the data on irrigation operations (i.e., discharges, reservoir levels, etc.) by computer into the appropriate flow duration, head duration, and energy curves for use in subsequent design work.

(b) *Flowchart II* - to examine alternative turbine-generator configurations with the objective of maximizing *annual energy production* from available irrigation discharges (para 2.3). After screening to ensure that each scheme would meet minimum requirements (*Annex A*), the configuration with the highest energy productivity was selected.

(c) *Flowchart III* - to classify the schemes according to the key design parameters of head and available discharge levels, and to develop a set of standard design parameters and performance specifications for electro-mechanical equipment i.e., turbines, generators, etc.). The database for the standardization consisted of the entire group of schemes (paras. 2.5 and 2.6).

(d) *Flowchart IV* - to minimize the investment required to develop the schemes based on the configuration selected in the preceding stages. The aim was to streamline designs for the main components (Chapter III). 16/ Also at this stage, a preliminary grid-tie arrangement was defined to "export" the energy into the local grid.

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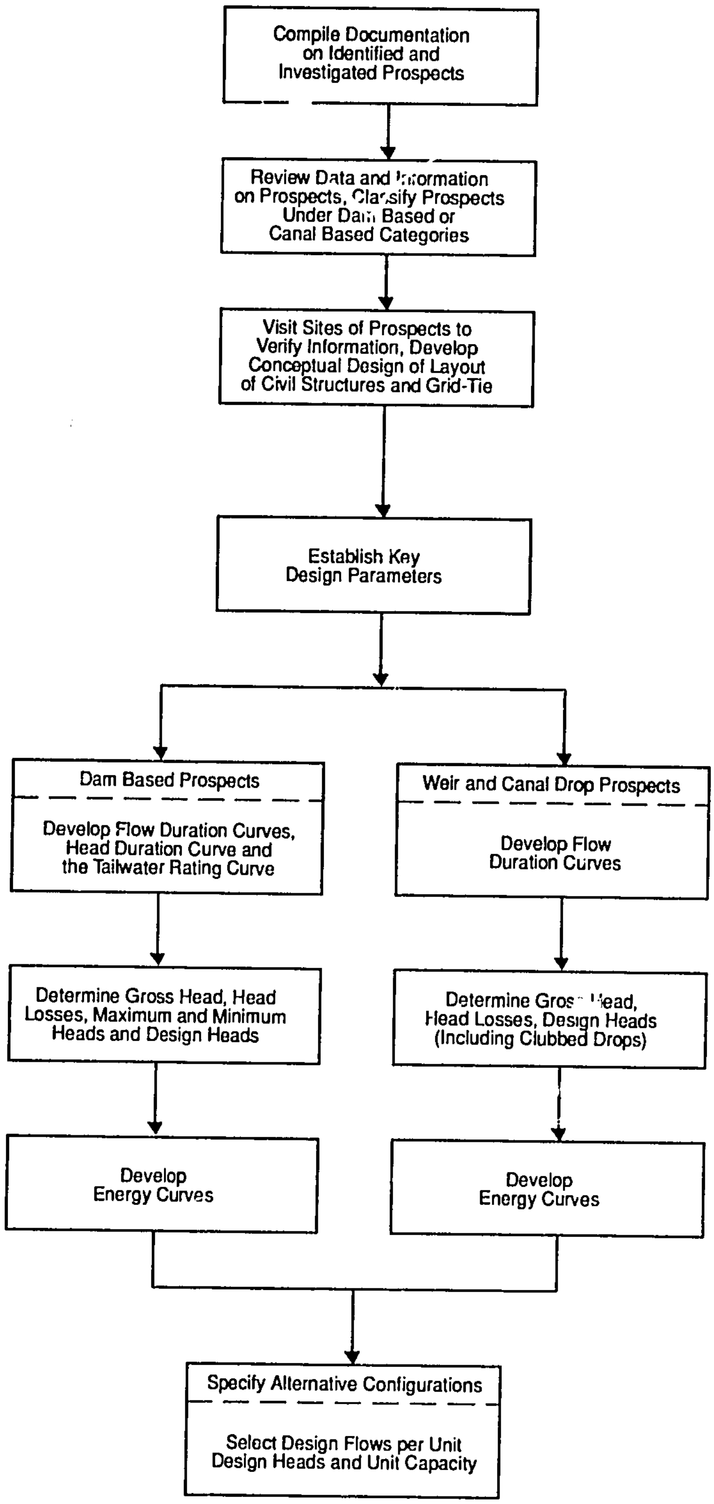
16/ The irrigation storage structures are already in place. Hence no additional investment is required to regulate the discharges which are available for nine to ten months each year; consequently, mini-hydro schemes with high plant load factors can be established with a minimum of additional infrastructure.

I

## PROCEDURE FOR PRELIMINARY DESIGN OF PROSPECTIVE MINI-HYDRO SCHEMES

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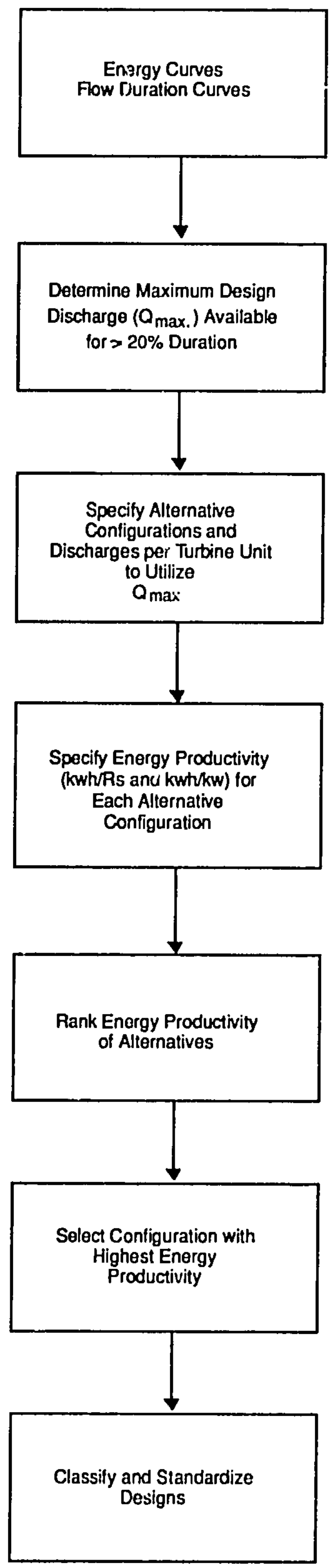
# II

# PROCEDURE FOR SCREENING AND OPTIMIZING ALTERNATIVE DESIGNS OF MINI-HYDRO SCHEMES

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## B. Preliminary Analysis and Design

2.3 After verifying the accuracy and reliability of site specific data in the proposals submitted by the SEBs, reviewing key design parameters for each scheme, and developing conceptual layouts for the schemes, either individually or in groups, the following procedure was used to develop preliminary designs:

(a) the site specific data (i.e., hydrological, topographical, geological, and layout of local grid, etc.,) was collated and evaluated. Computerized flow duration curves were prepared for all schemes. For dam based sites, the design head was established after a comprehensive analysis of the relationship between discharge levels and the level of the reservoir and tailwater respectively (*Annex B*).

(b) energy curves for each scheme were produced by integrating the area under flow duration curve for a specified head. By examining the shape of both the flow duration and energy curves respectively, a number of alternative configurations were specified assuming the application of multi-unit turbine flow control (Box 2.1). One key factor in determining the number of units for canal drop schemes usually was the canal width; in the majority of cases, two or three units of similar capacity were specified for analysis (*Box 2.2*). For dam based schemes, the key factors were the number of sluices that had been made available by the irrigation authorities for the scheme, the maximum throughput capacity of each sluice, and the need to retain some sluices to by-pass the turbines during periods when irrigation discharges would exceed the requirement for power generation or the shut-down of the turbines;

(c) estimates of the energy production capability under each of the alternative configurations were derived from the energy curve, assuming an 80% efficiency of the turbine-generator units. The annual value of the energy produced was computed based on Rs. 0.80/kWh (*Chapter V*); also preliminary estimates of the capital costs of each configuration were made. 17/

(d) benefit-cost ratios for each unit were estimated, and used to establish the minimum unit load factor for screening purposes (*Figure 2.1*); only units with benefit cost rations higher than 1.0 were retained. For the majority of schemes, the cut-off point for Rs. 0.80/kWh was determined to be the 20% exceedance level on the flow duration curve. For dams based schemes, there usually were two or more configurations involving different capacities to screen. After the analysis of B/C ratios has established the optimal number of units per scheme, the relative energy productivity of the different configurations were analyzed along the lines shown in *Box 2.3*. The plant size for each scheme was selected to maximize energy productivity.

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17/ The approach used to develop preliminary cost estimates was to start with cost estimates for the basic turbine-generator set-up. The data on equipment costs were obtained from a variety of local and international sources, including from the SEBs and manufacturers in India. On subsequent analysis of capital costs, the cost of turbine and generator was found on average to be 50-60% of total capital costs of an irrigation based mini-hydro scheme.

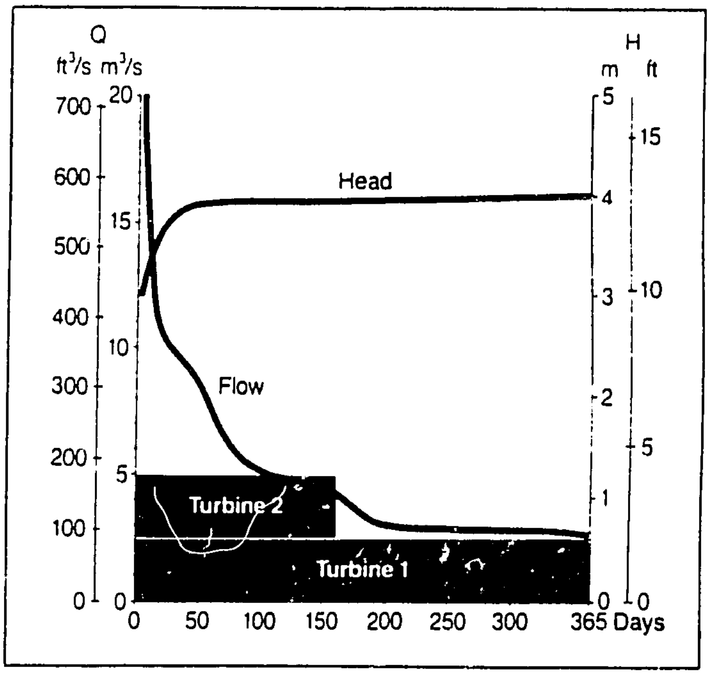
**Multi-Unit Flow Control for Irrigation Based Mini-Hydro Schemes**

The flow duration curve indicates the percentage of time that the available discharges at a given site is exceeded (i.e., percentage exceedance levels). The multi-unit flow control concept assumes that a number of fixed blade turbines would be used to harness the energy from the discharges. The turbines would operate at or near the design peak efficiency, and one or more units would be started or stopped according to the available flow. Usually, turbines of equal sizes are selected; each turbine becomes the back-up unit for the others during maintenance, etc.

The total output of energy at a given site can be increased either by: (i) adding more units of the same size; or (ii) introducing larger capacity units.

As indicated in the graph below, during periods when the flow of irrigation water is high, there is a corresponding rise in the tailwater level; this leads to a slight reduction in net head. The efficiency of the turbines can be maintained by adjusting the blade angle. A simple hand cranking mechanism would be suitable for the purpose.

The optimal number of equal sized turbine units is established based on economic benefit-cost analysis; the benefit-cost ratio for each unit has to be equal or greater than 1.0. The benefits are defined in terms of the annual energy produced times the economic value of the energy, and the costs are determined based on the annual costs of generation (i.e., fixed plus operating and maintenance costs).




Box 2.1

**Typical Preliminary Design Procedure for Canal Drop Schemes: The Maddur scheme, Karnataka**

The proposed Maddur scheme is located at a bend in the Maddur Branch Canal of the Visveswaraiah Main Canal in the Mysore District of Karnataka. The available head at the location is 13.4 meters. Details on the proposed layout are presented in Box 3.5 below.

Flow Duration Curve (Fig. 2.2): The flow duration curve was developed based on 10 years of data provided by KPC. The preferred configuration was two equal sized units. The maximum discharge level for design purposes, (fixed at the 20% exceedance point on the curve) was about 17 cumecs. Using turbines with fixed blades, it was apparent that the design discharge per unit would be 8.5 cumecs. For two units, the discharge required at full capacity would be 8.5 cumecs for the first unit, and 8.5 cumecs for the second. Assuming that the generators would be rated for 10% overload capacity, the installed capacity for the scheme would be 2 x 1000 kW. Also the available head, taking into account losses due to friction in the water conveyance system, was estimated to be 13.4 meters.

Energy Curve (Fig. 2.3): The energy curve was prepared for a design head of 13.4 meters. The energy output represents the area under the flow duration curve, assuming a 100% conversion efficiency; all estimates of the energy output were adjusted downwards assuming that the efficiency of the turbine-generators would be 80%. Hence the energy output would be 6.3 GWh for the first unit, and 2.63 GWh for the second unit. From the energy curve, it is clear also that the additional energy that could be recovered from the remaining flows (i.e., over 17 cumecs) would be insignificant.

Benefit-Cost Ratio for Units: The B/C ratios were estimated for each unit to determine the minimum load factor that would be viable assuming a Rs. 0.80/kWh economic value of energy. It was determined that below 20% unit load factor, it would not be economic to harness additional energy from the flows. The B/C ratios for the two units under the final configuration (i.e., 2 x 1000 kW) are indicated below.

| Unit | Unit Load Factor (%) | Energy Output (GWh) | B/C Ratio |
|---|---|---|---|
| 1 | 72 | 6.31 | 3.58 |
| 2 | 30 | 2.63 | 1.49 |
| Plant | 51 | 8.94 | 2.54 |

Box 2.2

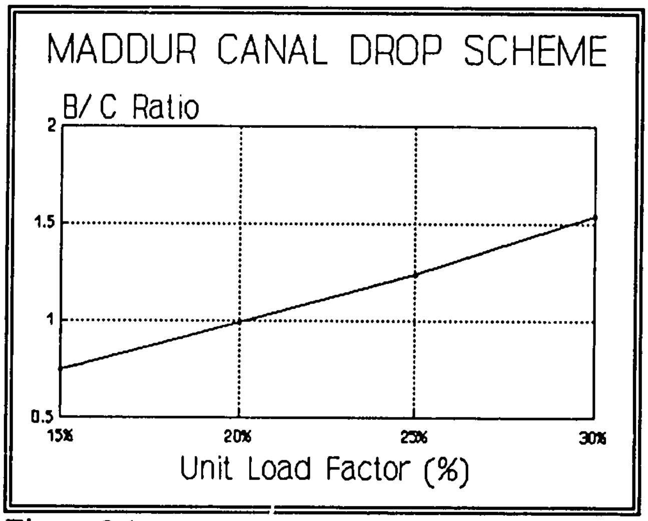



Figure 2.1

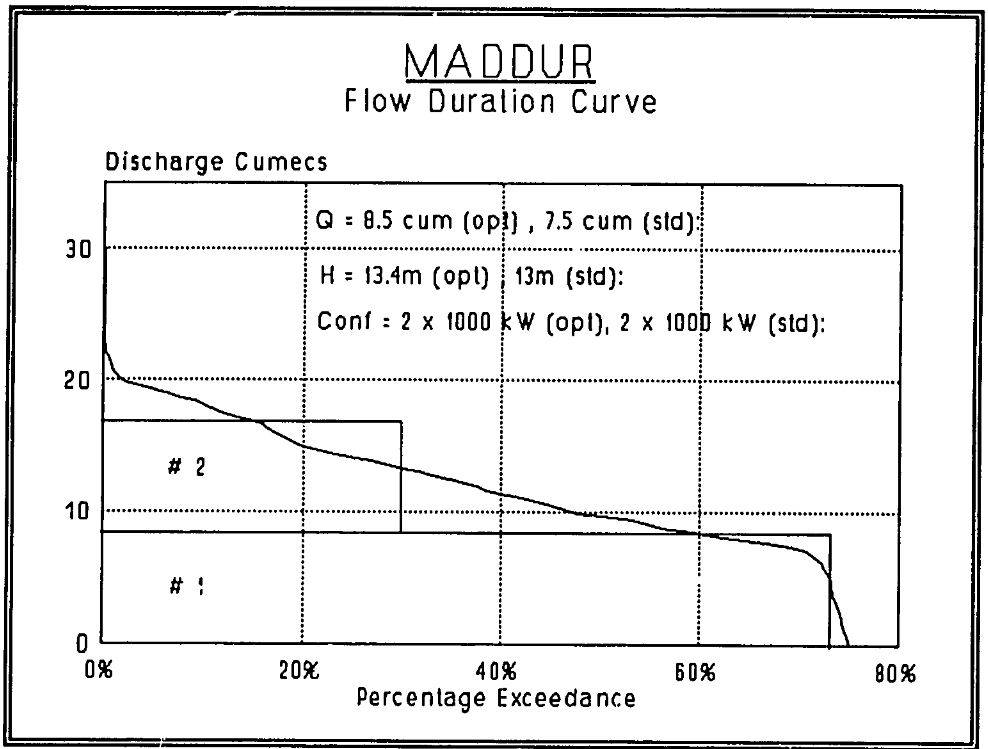



Figure 2.2

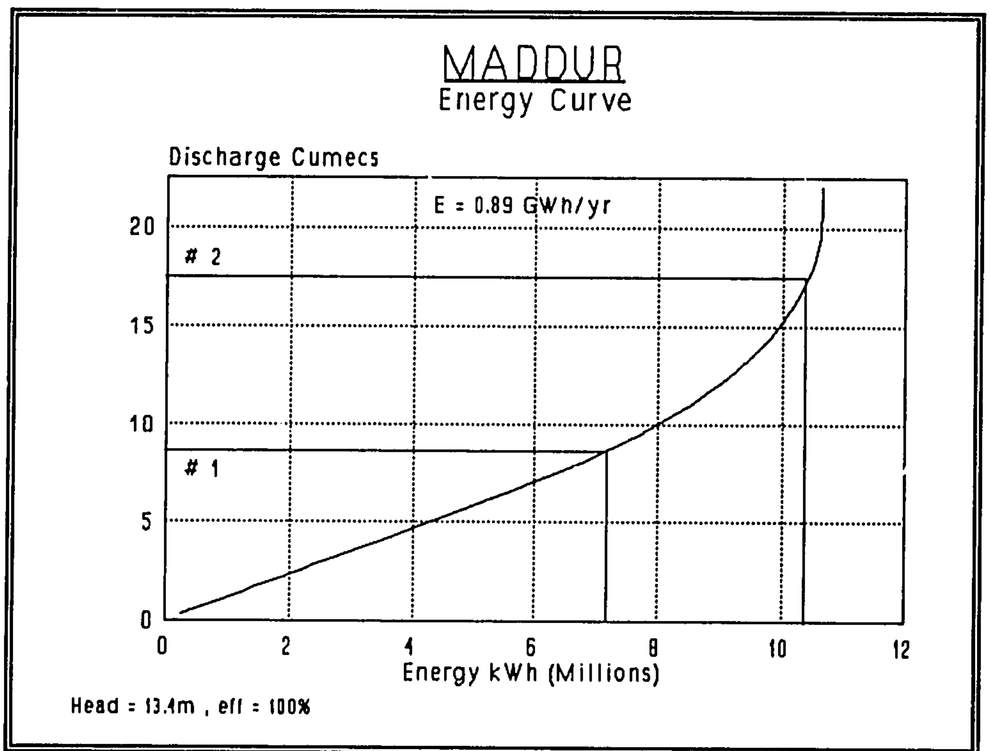



Figure 2.3

**Typical Preliminary Design Procedure for Dam Based Schemes: The Sathanur Dam Scheme, Tamil Nadu**

The Sathanur Dam is located at a reservoir on the River Ponniar; the average annual yield from the catchment (10,826 $km^2$) is $410x10^6m^3$ which is released through five dam sluices of 1.52m width and 1.83m height. About 13 cumecs is discharged continuously from the sluices into two canals. Two of the existing five sluices would be utilized for the proposed mini-hydro scheme. The powerhouse would be located adjacent to the dam, where the available head is 27.7 meters. The original proposal was to install 2 x 7.5 MW, and to produce 27.7 GWh/year.

Flow Duration Curve (Fig. 2.4): The revised proposal is based on daily discharge data at Sathanur over a 15 year period. From the flow duration curve, it is apparent that units could be installed to utilize 10 cumecs each; 10 cumecs would be available for the first unit for up to 73% duration; an additional 10 cumecs would also be available to the second unit for about 30% duration; and so on up to 70 cumecs for less than 10% duration.

Head Duration Curve (Fig 2.5): The head was found to be 20 meters for 60-70% duration, between 20 to 25 meters for 50-60% duration, and 25 to 30 meters for 35-50% duration. A design head of 27.5 meters, which corresponds to the 40% duration, was selected. Hence for this study, the design head is assumed to be 27.5 meters. Hence, by adopting a design discharge of 10 cumecs per unit, units of 2500 kW would be feasible.

Energy Curve (Fig. 2.6): The energy curve, produced based on the average flows and the design head, provides the following information on the incremental energy that could be recovered at the dam by increasing the design discharge level in steps of 10 cumecs. Assuming 80% efficiency of the turbine-generator sets, the energy output and B/C ratios from a multi-unit configuration would be (Fig. 2.7):

| UNIT | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Energy (GWh) | 14.0 | 8.0 | 2.0 | 1.4 | 1.0 | 0.8 | 0.2 |
| B/C Ratio | 2.06 | 1.69 | 0.42 | 0.29 | 0.21 | 0.17 | 0.04 |

Analysis of Annual Energy Productivity: The original proposal to install 2 x 7500 kW requires the use of two sluices to handle the entire 70 cumecs of discharge from the dam; this would not be feasible. However, the above analysis of unit benefit-cost ratios indicated clearly that it would not be economic to use more than two units. After some iteration and analyses of benefit-cost ratios of units in alternative configurations, the relative energy productivity with the two unit configuration for four alternatives were evaluated. As indicated below, the results confirm that the 2 x 2500 kW would have the highest energy productivity.

ANALYSIS OF ENERGY PRODUCTIVITY OF ALTERNATIVE CONFIGURATIONS

| Capacity (kW) | 2*2000 | 2*2500 | 2*3500 | 2*5000 a/ |
|---|---|---|---|---|
| Energy Output (GWh) | 19.2 | 22.5 | 24.0 | 25.6 |
| Plant Load Factor (%) | 0.6 | 0.5 | 0.4 | 0.3 |
| Cost Estimates | | | | |
| Civil Structures | 6.5 | 7.0 | 10.5 | 14.0 |
| Electro-Mech | 7.4 | 8.8 | 12.3 | 15.6 |
| Electricals | 9.3 | 11.2 | 18.4 | 24.4 |
| Grid-Tie | 2.7 | 2.7 | 2.7 | 2.7 |
| Total | 25.9 | 29.7 | 43.9 | 56.7 |
| Investment (Rs./kW installed) | 6489.0 | 5940.0 | 6271.4 | 5670.0 |
| Energy Prod. (kWh p.a/100 Rs.) | 74.1 | 75.7 | 54.7 | 45.2 |

a/ synchronous generators were specified for units with capacity greater than 3.5 MW.

Box 2.3

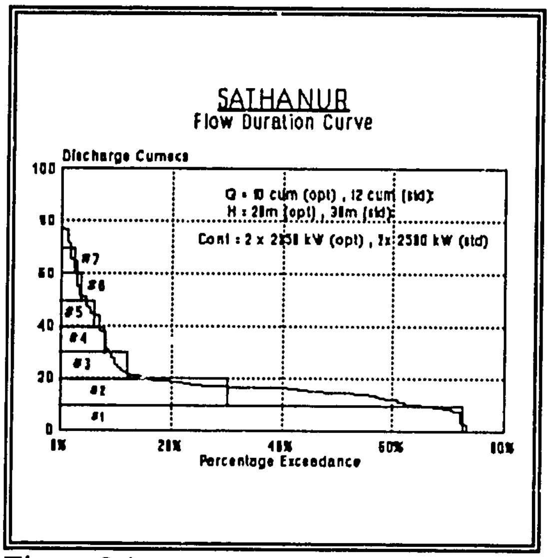



Figure 2.4

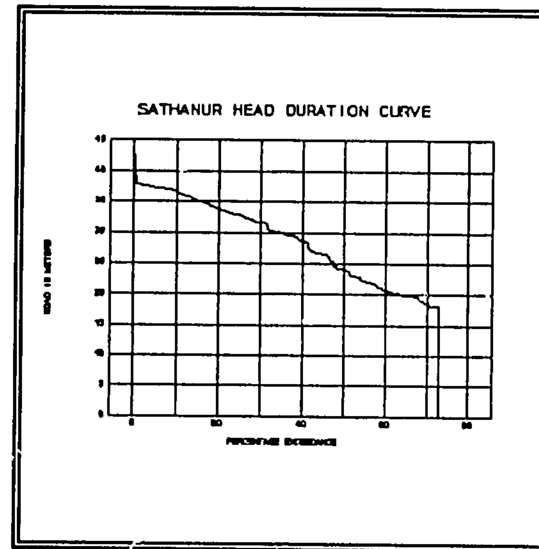



Figure 2.5

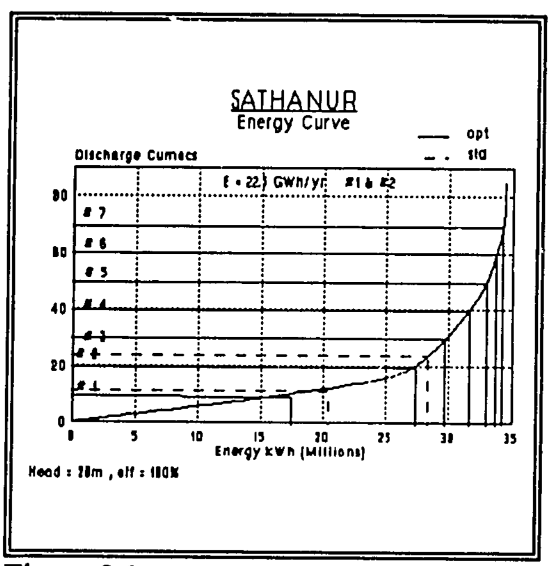



Figure 2.6

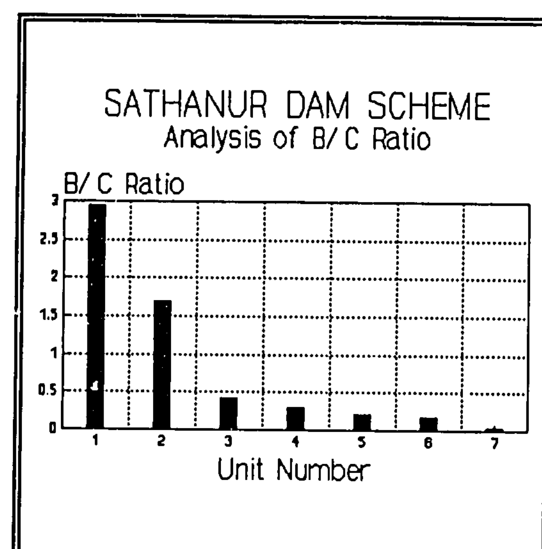



Figure 2.7

## C. Standardization

2.4 The scale of operation of the mini-hydro prospects is small relative to the size of central power stations in the respective states. Therefore, it is not cost-effective to develop one-off designs for each prospect. Furthermore, the type and performance of turbines for mini-hydro applications vary significantly from manufacturer to manufacturer; some degree of flexibility is required at this stage of design so that eventually it would be possible to consider alternative configurations of turbines that also would satisfy minimum performance specifications. Given the advantages of some degree of standardization, it was considered useful to develop a set of minimum performance specifications to correspond to the range of available heads and discharges for the prospects covered by this study.

2.5 The procedure outlined in *Flowchart III* was used, as described below:

(a) *Classification of Schemes by Head and Discharge.* First, the schemes were grouped into eight standardized head categories. Second, for each category of standardized head, the schemes were allocated to sub-categories based on a set of standardized discharges per unit (*Table 2.2*).

(b) *Development of Standardized Specifications for Turbines.* The runner specifications (i.e., the maximum operating speed of turbine, minimum diameter of runners) for each category of design head and discharge was computed and compared with those indicated on reference monographs (*Annex C*) which had been obtained from international engineering design firms and local manufacturers in India. 18/ A set of eight standardized runner diameters were developed for the turbine requirements of the schemes, ranging in diameter from 2800 mm. to 1000 mm (*Table 2.3*) for fixed blade tubular turbines. For the most part, runner diameters were uniform for schemes associated with the major irrigation systems. For example, due to standardization, all schemes on the Guntur and Adanki Branch Canals of the Nagarjuna Sagar system in Andhra Pradesh would handle 22.5 cumecs per turbine-generator unit; therefore a common runner diameter of 2000 mm was specified.

(c) *Development of Standardized Specifications for Induction Generators.* Induction (asynchronous) generators, essentially induction motors which are driven at slightly above synchronous speed, were specified for all schemes. The analysis indicated that induction generators were required for with eight capacities in the range 350 kW to 3500 kW. 19/ The operating speed of induction generators were specified; the difference between the rotating speeds of the turbine and generator were used to establish the specification for speed increasing mechanisms. The goal was to keep

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18/ Use of the data from specific manufacturers and engineering firms does not necessarily imply endorsement of them.

19/ The primary function of the irrigation based mini-hydro schemes is to provide energy to the remote sections of the grid. Hence, induction generators, which require no separate excitation source since they draw magnetizing current from the grid, were considered to be appropriate. Induction generators are commercially available in India. Several units of 2 and 3 MW capacity have been installed in Tamil Nadu for irrigation based mini-hydro schemes at Lower Bhavani(RBC), Vaigai, and Pykara Dams respectively.

the speed of the turbines as high as possible and to minimize the gearbox ratio by maintaining the lowest feasible speed for the generators.

(d) *Revision of Preliminary Designs Using Standardized Specifications.* The preliminary designs for each scheme were adjusted to reflect the standardized specifications for design head, design discharge levels, and installed capacity.

Table 2.1: Overview of Turbine Performance Specifications

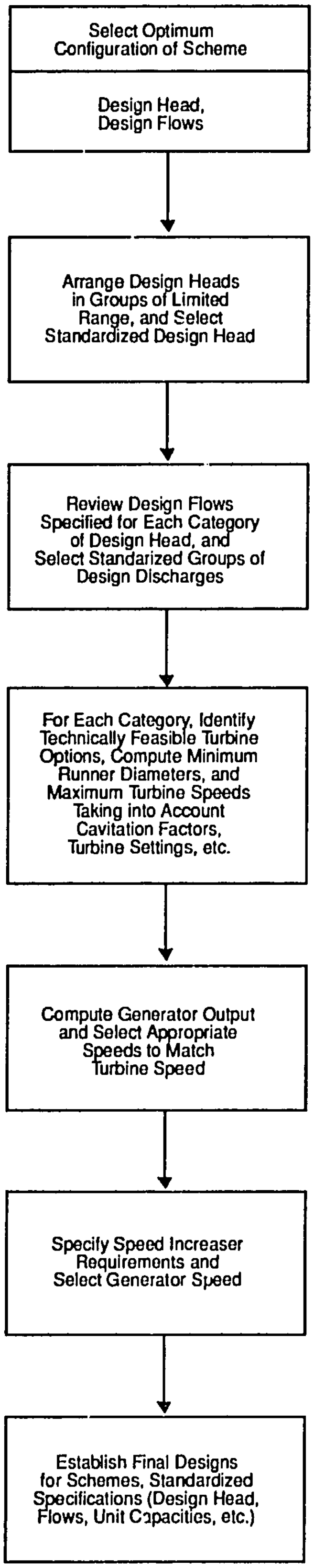
| Type of Turbine | Rated Head -Hr (m) | Min./Max Head (% of Hr) | Rated Power -Pr (kW) | Min./Max. Capacity (% of Pr) | Remarks |
|---|---|---|---|---|---|
| Vertical Fixed Blade Propeller | 2-20 and over | 55-125 | 250-15,000 and aover | 30-115 | may be operated up to 140% of rated head depending on turbine setting |
| Vertical Semi-Kaplan with Adjustable Blades (propeller) | 2-20 and over | 45-150 | 1000-15,000 | 10-115 | |
| Vertical Francis | 8-20 and over | 50-125 | 250-15,000 | 35-115 | Minimum rated head is 8 meters |
| Horizontal Francis | 8-20 and over | 50-125 | 250-2000 | 35-115 | Minimum rated head is 8 meters; maximum capacity is 2000 kW |
| Tubular (adjustable blades/fixed gates) | 2-18 | 65-140 | 250-15,000 | 45-115 | |
| Tubular (fixed blade runner with wicket gates) | 2-18 | 55-140 | 250-15,000 | 35-115 | |
| Bulb | 2-20 | 45-140 | 1000-15,000 | 10-115 | minimum capacity is 1000 kW |
| Rim | 2-9 max. | 45-140 | 1000-8000 | 10-115 | minimum capacity is 1000 kW |
| Right Angle Drive Propeller | 2-18 | 55-140 | 250-2000 | 45-115 | maximum capacity is 2000 kW |
| Open Flume | 2-11 max. | 90-110 | 250-2000 | 30-115 | maximum capacity is 2000 kW |
| Closed Flume | 2-20 | 50-140 | 250-3000 | 35-115 | maximum capacity is 3000 kW |
| Crossflow | 6-20 | 50-125 | 250-2000 | 10-115 | maximum capacity is 2000 kW |

Hr, the Rated Head, is defined as the head at which full gate output equals the rated output of the generator.

Source: ESMAP

# III

## PROCEDURE FOR STANDARDIZATION OF DESIGNS FOR PROSPECTIVE MINI-HYDRO SCHEMES

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## Table 2.2: Standardized Specifications for Turbines

| | SCHEME NAME | STANDARDIZED HEAD (METERS) | STANDARDIZED DISCHARGE (CUMECS) | NO. OF UNITS | TURBINE RUNNER DIA. (MM) | ROTATING SPEED TURBINE (RPM) | ROTATING SPEED GENERATOR (RPM) | GENERATOR CAPACITY (kW) |
|---|---|---|---|---|---|---|---|---|
| | Chanarthal | 3.0 | 50.0 | 4 | 2800 | 100 | 600 | 1000 |
| | Thablan | 3.0 | 50.0 | 6 | | | | 1000 |
| | Chupki | 3.0 | 30.0 | 2 | 2500 | 187.5 | 750 | 650 |
| | Dolowal | 3.0 | 30.0 | 2 | | | | 650 |
| | Babanpur | 3.0 | 30.0 | 2 | | | | 650 |
| | ChakBal | 3.0 | 30.0 | 2 | | | | 650 |
| | Narangawal | 3.0 | 30.0 | 3 | | | | 650 |
| | Kila | 3.0 | 30.0 | 2 | | | | 650 |
| | Tugal | 3.0 | 22.5 | 3 | 2000 | 187.5 | 750 | 350 |
| | Salar | 3.0 | 22.5 | 2 | | | | 350 |
| 11 | Sidhana | 3.0 | 12.0 | 1 | 1400 | 187.5 | 750 | 350 |
| | Dalia | 4.25 | 30.0 | 2 | 2500 | 250 | 750 | 1000 |
| | GBC 3 | 4.25 | 22.5 | 2 | | | | 650 |
| 3 | ABC 1 | 4.25 | 22.5 | 2 | | | | 650 |
| | Lower Manair | 7.0 | 22.5 | 2 | | | | 1500 |
| | GBC 1 | 7.0 | 22.5 | 3 | 2000 | 214 | 600 | 1250 |
| | GBC 4 | 7.0 | 22.5 | 2 | | | | 1000 |
| | Kuttiyadi 2 | 7.0 | 12.0 | 2 | 1400 | 333 | 600 | 650 |
| | Kuttiyadi 3 | 7.0 | 12.0 | 2 | | | | 650 |
| | SBC1 | 7.0 | 7.5 | 3 | | | | 350 |
| | SBC2 | 7.0 | 7.5 | 3 | | | | 350 |
| | SBC3 | 7.0 | 7.5 | 3 | | | | 350 |
| | SBC4 | 7.0 | 7.5 | 3 | | | | 350 |
| | SBC6 | 7.0 | 7.5 | 1 | | | | 350 |
| 11 | Attehala | 7.0 | 7 5 | 1 | | | | 350 |
| | GBC 2 | 10.0 | 22.5 | 3 | 2000 | 187.5 | 750 | 1250 |
| | ABC 2 | 10.0 | 22.5 | 2 | | | | 1250 |
| | Lock-In-Sula | 10.0 | 22.5 | 2 | | | | 1500 |
| | Malaprabha | 10.0 | 12.0 | 2 | | | | 650 |
| | Peechiparal | 10.0 | 12.0 | 2 | 1400 | 333 | 600 | 650 |
| | Kilara | 10.0 | 12.0 | 2 | | | | 650 |
| | Kabini | 10.0 | 12.0 | 3 | | | | 650 |
| | SBC5 | 10.0 | 5.0 | 3 | 1000 | 333 | 600 | 350 |
| 9 | Mangalam | 10.0 | 5.0 | 1 | | 333 | 600 | 350 |
| | Brindavan | 13.0 | 30.0 | 3 | 2500 | 375 | 600 | 3500 |
| | Nugu | 13.0 | 12.0 | 2 | 1400 | 428 | 600 | 1000 |
| | Devrebelerkere 1 | 13.0 | 12.0 | 1 | | | | 1000 |
| | Maddur | 13.0 | 7.5 | 2 | 1250 | 428 | 600 | 1000 |
| | Mudhol | 13.0 | 7.5 | 1 | | | | 1000 |
| 6 | Thirimurthy | 13.0 | 7.5 | 3 | | | | 650 |
| | L. Bhavani | 15.0 | 30.0 | 2 | 2500 | 250 | 750 | 3500 |
| | Maniyar | 15.0 | 22.5 | 6 | 2000 | 300 | 600 | 2500 |
| | Kuttiyadi 1 | 15.0 | 12.0 | 2 | 1400 | 428 | 600 | 1500 |
| | Harangi | 15.0 | 12.0 | 3 | | | | 1500 |
| | Perunchani | 15.0 | 7.5 | 2 | 1250 | 428 | 600 | 650 |
| | Rajankollur | 15.0 | 7.5 | 3 | | | | 650 |
| 7 | Anveri | 15.0 | 7.5 | 2 | | | | 650 |
| | Amaravathy | 21.0 | 12.0 | 2 | 1400 | 428 | 600 | 2000 |
| 2 | Peechi(CBH) | 21.0 | 7.5 | 1 | 1250 | 428 | 600 | 1500 |
| | Peechi(RBH) | 30.0 | 12.0 | 2 | 1400 | 500 | 750 | 2500 |
| | Sathanur | 30.0 | 12.0 | 2 | | 500 | 750 | 2500 |
| 3 | Aliyar | 30.0 | 5.0 | 2 | 1000 | 500 | 750 | 1250 |
| 52 | | | | 121 | | | | |

SOURCE: ESMAP computations

## TABLE 2.3 STANDARDIZED DESIGN SPECIFICATIONS FOR SCHEMES

| STATE/SCHEME | STANDARDIZED DESIGN SPECIFICATIONS | | | |
|---|---|---|---|---|
| | Head (meters) | Discharge (m3) | Capacity (kW) | Energy Production (GWh/yr. @ 80% eff.) |
| **ANDHRA PRADESH** | | | | |
| Adanki BC 1 | 4.25 | 22.5 | 2*650 | 3.64 |
| Adanki BC 2 | 10 | 22.5 | 2*1250 | 6.8 |
| Guntur BC 1 | 7 | 22.5 | 3*1250 | 17 |
| Guntur BC 2 | 10 | 22.5 | 3*1250 | 19.8 |
| Guntur BC 3 | 4.25 | 22.5 | 2*650 | 6.4 |
| Guntur BC 4 | 7 | 22.5 | 2*1250 | 10.5 |
| Lock-In-Sula | 10 | 22.5 | 2*1500 | 16.48 |
| Lower Manair | 7 | 22.5 | 2*1500 | 16 |
| **KARNATAKA** | | | | |
| Attehala | 7 | 7.5 | 1*350 | 2.8 |
| Anveri | 15 | 7.5 | 2*650 | 5.26 |
| Brindavan | 13 | 30 | 3*3500 | 62 |
| Dveverebelekere | 13 | 12 | 1*1000 | 9.07 |
| Harangi | 15 | 12 | 3*1500 | 14.52 |
| Kabini | 10 | 12 | 3*650 | 6.25 |
| Kilara | 10 | 12 | 2*650 | 5.8 |
| Maddur | 13 | 7.5 | 2*1000 | 8.3 |
| Malaprabha | 10 | 12 | 2*1000 | 8.08 |
| Mudhol | 13 | 7.5 | 1*1000 | 4.86 |
| Nugu | 13 | 12 | 2*1000 | 6.15 |
| Rajankollur | 15 | 7.5 | 3*650 | 6.33 |
| Shahpur BC 1 | 7 | 7.5 | 3*350 | 5.1 |
| Shahpur BC 2 | 7 | 7.5 | 3*350 | 3.9 |
| Shahpur BC 3 | 7 | 7.5 | 3*350 | 3.65 |
| Shahpur BC 4 | 7 | 7.5 | 3*350 | 4.15 |
| Shahpur BC 5 | 10 | 7.5 | 2*650 | 4.88 |
| Shahpur BC 6 | 7 | 7.5 | 1*350 | 2 |
| **KERALA** | | | | |
| Kuttiyadi PH1 | 15 | 12 | 2*1500 | 17.1 |
| Kuttiyadi PH2 | 7 | 12 | 2*650 | 5.7 |
| Kuttiyadi PH3 | 7 | 12 | 2*650 | 5.7 |
| Peechi I (CBU) | 21 | 10 | 1*1500 | 10 |
| Peechi II (RBU) | 30 | 12 | 2*2500 | 17.1 |
| Mangalam | 10 | 5 | 1*350 | 1.3 |
| Maniyar | 15 | 22.5 | 6*2500 | 57.1 |
| **TAMIL NADU** | | | | |
| Aliyar | 30 | 5 | 2*1250 | 9.32 |
| Amaravathy | 21 | 12 | 2*1000 | 10.58 |
| Lower Bhavani | 15 | 30 | 2*3500 | 24.25 |
| Peechiparai | 10 | 12 | 2*650 | 5.95 |
| Perunchani | 15 | 7.5 | 2*650 | 5.1 |
| Sathanur | 30 | 12 | 2*2500 | 21.82 |
| Thirumurthy | 13 | 7.5 | 3*650 | 7.73 |
| **PUNJAB** | | | | |
| Babanpur | 3 | 30 | 2*650 | 7 |
| Chakbhai | 3 | 30 | 2*650 | 7.2 |
| Chanarthal | 3 | 50 | 4*1000 | 29.25 |
| Chupki | 3 | 30 | 2*650 | 30 |
| Dalla | 4.25 | 30 | 2*1000 | 9.2 |
| Dolowal | 3 | 30 | 2*650 | 8.12 |
| Kila | 3 | 30 | 2*650 | 6.48 |
| Narangwal | 3 | 30 | 3*650 | 8.8 |
| Thablan | 3 | 50 | 6*1000 | 44.2 |
| Tugal | 3 | 22.5 | 3*350 | 6.5 |
| Salar | 3 | 22.5 | 2*350 | 3.44 |
| Sidhana | 3 | 12 | 2*350 | 4.12 |

SOURCE: ESMAP Computations

## III. DESIGN AND COSTING OF FACILITIES

### A. Design of Civil Structures

3.1 The primary objective was to minimize the costs of civil works. The original layouts and designs for the main civil structures were revised according to three criteria: (i) structural modifications to the existing irrigation facilities were reduced to a minimum; (ii) layouts of civil structures were simplified to facilitate construction, specifically so that schemes would at most be implemented within two irrigation seasons; and (iii) layouts of water conveyance structures were realigned so as not to cause any permanent loss of productive agricultural land or other adverse environmental impacts. To the extent possible for each category of mini-hydro scheme, a set of standard designs were developed for main civil structures, particularly the powerhouse structures, and the water intake and conveyance structures.

*Powerhouses*

3.2 Regardless of the category and size of scheme (i.e., dam based, canal drop, etc.), the current powerhouse designs for irrigation based mini-hydro schemes in India are generally scaled down versions of structures that are used for large conventional hydro stations. Typically, there are redundancies in the design of the powerhouses, which are due in large part to the provisions made for an overhead crane and an array of electrically operated equipment (e.g., pumps, servo-motors), instrumentation to control operations such as automatically operated gates (i.e., to regulate water levels on the existing irrigation canal, and to open the main canal as a bypass for water in the event the mini-hydro plant trips or is shut-down).

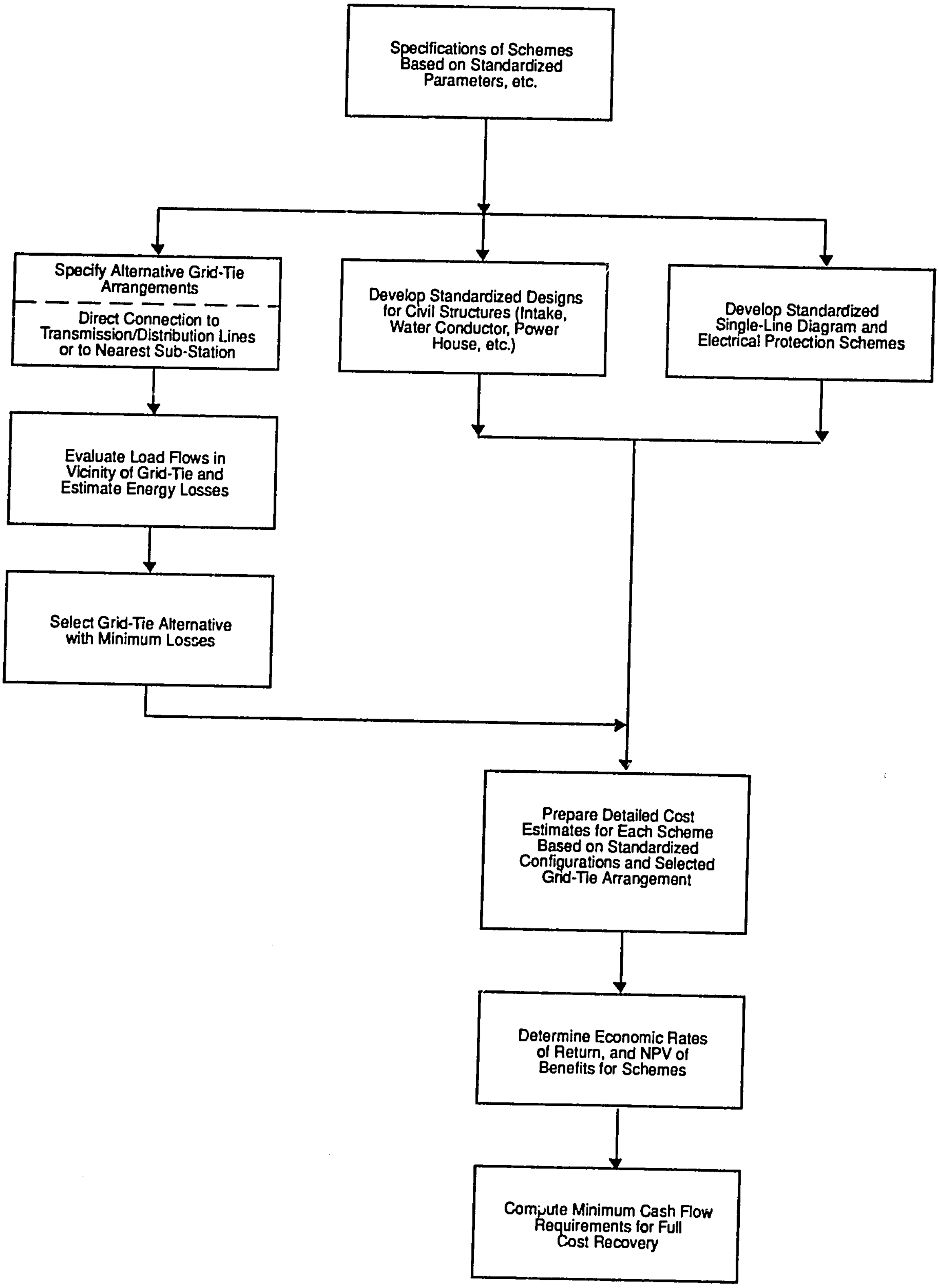
3.3 Two options were defined during the study. The first option was to eliminate completely the powerhouse structure if the generators used are manufactured for outdoor installation. For the option without a powerhouse, all controls and instrumentation would be installed in a small cubicle or a metal-clad switchboard that would also be built for outdoor installation. The second option was to retain a simplified powerhouse which would contain the minimum facilities to protect key parts of the mini-hydro equipment, particularly the generators and instrumentation; there would be no overhead crane. The powerhouse would consist of a small cubicle with a provision in the roof, in the form of a removable hatch for the use of a mobile crane to hoist the electro-mechanical equipment during installation or maintenance operations. Both options (i.e., with or without the powerhouse structures) are illustrated in the technical drawings (*Annex G*). Nevertheless, to be conservative for cost estimation purposes, a simplified powerhouse structure has been included for each scheme.

*Water Intake and Conveyance Structures.*

3.4 The original layouts and designs for the water intake and conveyance facilities were simplified to facilitate construction. To the extent possible, standardized designs were to be developed for the penstocks, closed conduits, and open channels. The main features of the alternative designs for the different categories of mini-hydro schemes are as follows.

# IV

## PROCEDURE FOR FINALIZING DESIGN SPECIFICATIONS AND CAPITAL COST ESTIMATES AND FOR EVALUATING VIABILITY OF PROSPECTIVE SCHEMES



3.5 *Dam based schemes*. Since the majority of the prospective dam based schemes are located in Karnataka and Tamil Nadu, the revised layouts and designs were prepared after a critical review of the original proposals in the two states. In Karnataka, the original proposals typically require extensive excavation through rock in order to construct entirely new intakes and tunnels to by-pass the sluices in the existing dams. By contrast in Tamil Nadu, the excavation work is eliminated in the original proposals which make use of the existing sluices as intake structures; the penstocks would be directly attached to the sluices.

3.6 The revised layout further refines the approach taken in Tamil Nadu and uses the existing sluices as intake structures; each sluice would be fitted with a trash rack, gate or stoplog, hoists, and a "bellmouth" made of reinforced cement concrete (RCC). Steel penstocks would be anchored into the existing sluices, and encased in backfill concrete. 20/ A conically shaped draft tube would be installed at the outlet from the turbines, to divert the water into a rectangular pool. The rectangular pool, which would maintain the water level in the draft tube, would empty out into the existing irrigation canal. To achieve design discharge levels for a few schemes e.g., Brindavan), penstocks would need to be installed in all sluices. In such cases, special by-passes would be incorporated into the penstocks at a suitable point upstream of the turbines to allow for spilling in the event the turbines are shut down (Annex C). As indicated in *Box 3.1*, significant savings in capital costs would be realized by using the simplified layouts and powerhouse designs for dam based schemes.

**Minimizing Civil Works Cost of Dam Based Schemes: The Brindavan Scheme, Karnataka**

The original layout involves extensive civil works (i.e., excavation of rock) to construct a by-pass tunnel to divert water from the reservoir through a powerhouse and into the existing canal. The revised layout eliminates the tunnel by using the existing irrigation sluices as the intake for the mini-hydro scheme.

At 1990 prices, the original layout would require an expenditure of Rs. 9.6 million, Rs. 3.6 million, and Rs. 3.4 million for the intake structure and tunnel, the powerhouse structure, and the tailrace/spillway structures respectively. By eliminating the tunnel and simplifying the powerhouse structure, the expenditure would be reduced to about Rs. 2.0 million; a savings of about Rs. 10 million in the cost of civil works. A detailed breakdown of cost estimates for civil works are presented in Annex E.

COMPARATIVE COSTS ESTIMATE FOR CIVIL WORKS

| CIVIL WORKS COMPONENT | ESTIMATES COSTS (Rs. million) | |
|---|---|---|
| | Original Layout | Revised Layout |
| Intake Channel | 7.00 | 0.43 |
| Inlet Tunnel | 2.65 | - |
| Powerhouse | 3.56 | 0.67 |
| Tailrace | 2.56 | 0.50 |
| By-pass/Spillway | 0.86 | 0.07 |
| Miscell. | 0.32 | 0.15 |
| | 16.95 | 1.82 |

SOURCE: Annex E.

Box 3.1

20/ The penstocks would be manufactured to fit the shape of the existing sluices. Typically, the initial section of the penstocks would be rectangular to fit the sluices exactly; a transitional section would be built to change the shape of the penstock from rectangular to square, and eventually to circular before the link-up with the turbines (refer to technical drawings for Lower Bhavani Scheme).

3.7 *Schemes at Irrigation Barrages and Diversion Weirs*. Two of the prospective schemes in this category are located in Kerala. One of them is associated with the tailrace discharges of the Kuttiyadi Dam which is used downstream for irrigation purposes. The other is located on the Maniyar barrage. The revised layout for dams based schemes were not applicable because there are no sluices. Except for the realignment to reduce the length of the water conveyance structures for the proposed schemes, and the use of closed conduits to obviate the need to permanently destroy agricultural land, there are no major differences between the original and revised designs for the Kuttiyadi Tailrace scheme (Box 3.2). The appropriate by-pass arrangement fo· the powerhouse would incorporate pressure regulator valves, as indicated in Annex C.

**Realignment of Water Conveyance Structures: Kuttiyadi Tailrace, Kerala**

The original layout would require extensive civil works: an intake structure consisting of a 7.6 meter long weir to divert the tailrace discharges into the power channel; a water conveyance structure comprising of a 805 meter long power channel (1.5 meter bed width) which would link up to a head regulator (5 m. x 2.6 m) equipped with a hoist, a forebay-underground RCC tank (21 m diameter, 11.5 m deep), a 100 meter long penstock (1.65 m diameter); and a 126 meter long aqueduct (dimensions 3.4 meter x 2.6 meter) which would run alongside the power channel. The powerhouse itself would be a large structure (32.75 x 9 x 9.75) and designed to fully enclose two 2500 kW turbine-generator units. The tailrace of the mini-hydro scheme, a 50 meter long channel, would discharge into the Peruvannunmuzhy Irrigation Reservoir.

After an extensive inspection of the area, especially the topography along the banks of the river, the layout was revised to take advantage of the following features: (i) the length of the river from the tailrace of the large power station to the irrigation river is 550 meters compared to over 800 meters for the power channel in the original proposal; (ii) there already exist drops at three sites along the river bed which if developed in a cascade, would provide the same cumulative head for power generation as in the original proposal.

Hence, a revised and simplified layout was prepared. Powerhouses would be located at three points along the river bed: the first would utilize a 15 meter drop and would be linked to the tailrace of the large power station by a closed conduit; the second would be located at a 5.5 meter drop along the river bed; and the third would also located at a 5.5 meter drop at the point where the river discharges into the irrigation reservoir. Small barrages (5 meter high) would be built at two points along the river bed to divert water into the intake structures for the second and third powerhouses. If necessary, flash boards, crest gates, and hoists would be installed at the main intake structure for the first powerhouse. In each case, the tailrace would consist of an open channel and a stop log to maintain the water level in the draft tube.

By realigning the ent e power channel, the revised layout: (i) reduces by 50% the length of water conductor ,stem; (ii) augments the overall energy production capacity at the site; and (iii) obviates the need to destroy existing coconut trees along the path of the power channel which would have resulted in a potentially adverse environmental impact.

Box 3.2

3.8 *Schemes at Single Canal Drops.* The revised layouts for schemes on single canal drops are intended to eliminate the use of a separate by-pass or diversion channel. In such cases, the existing canal would be used as the water conveyance structure; the equipment would be installed immediately downstream of the canal drop, and a simple by-pass arrangement would be incorporated at the intake structure. Alternatively, a penstock made out of precast concrete conduit would be installed along the sidewall of the existing canal. Both alternative layouts were evaluated for the prospective scheme at Kilara on the Visveswaraiah Left Bank Canal in Karnataka. In addition to reducing the environmental impact (i.e., loss of agricultural land), the savings in capital costs by eliminating the by-pass channel at Kilara was estimated to be Rs.3.6 million (Box 3.3).

**Eliminating By-Pass Channel for Canal Drop Schemes: Comparative Costs for Kilara Scheme, Karnataka**

As shown in Annex G, two alternatives to the original layout proposal have been prepared: (i) Alt 2 with a by-pass channel, but with the powerhouse relocated from the beginning to the end of the channel; and (ii) Alt 3 without the by-pass, using a 200 meter long pre-cast concrete conduit which would be laid along the sidewall of the existing canal. The estimated costs are as follows.

| CIVIL STRUCTURE | ESTIMATED COST (Rs. millions) ALT 2 WITH BY-PASS CHANNEL | ALT 3 WITHOUT BY-PASS |
|---|---|---|
| Gates | 1.0 | - |
| Intake | 1.0 | 0.7 |
| Channel | 5.9 | - |
| Penstock | - | 5.1 |
| Powerhouse | 0.5 | 0.7 |
| Tailrace | - | 0.1 |
| Miscell. | 2.5 | 0.7 |
| Total | 10.9 | 7.3 |

Box 3.3

3.9 *Schemes Utilizing Multiple Drops.* For such schemes, the main goal was to simplify construction requirements (*Box 3.4*). In general, there are no major differences between the original and revised designs, except were feasible to realign the channel to reduce the length of the water conveyance structures, and to use closed conduits to obviate the need to permanently destroy agricultural land. Bascule gates or crest gates would be installed slightly upstream of the canal drops to control the water level in the canal, and an intake which would be fitted with a trash rack and a stoplog. To maintain flows in the canal when the powerhouse is shut down, automatically regulated crest gates would be provided at the first drop structure (Annex C).

**Simplifying Construction of Multiple Drop Schemes: Guntur Branch Canal Cluster, Andhra Pradesh**

The original proposal by would establish four schemes along a 10 mile section of the canal. The first scheme would utilize 3 drops (total head 6.9 meters) on the first mile of the branch canal; the second would combine 4 drops (total head 8.85 meters) along the second mile; the third, 2 drops ( total head 3.71 meters) along the fifth mile; and the fourth, 3 drops (total head 8.52 meters) along the ninth mile. During the preliminary design and standardization process, it became apparent that the configuration of the second scheme could be changed from one scheme (i.e., combining 4 drops for total head 8.85 meters) to two schemes (i.e., combining 2 drops for head of 4.25 meters for each scheme). As a result, the length of the bypass channel was reduced by 250 meters, the cross-section of the by-pass channel was reduced, thereby allowing for significant savings in costs due to excavation of the channel and the powerhouse. Also, the change simplified the design of the intake structure and control mechanism (i.e, stop-log and trashrack) at the junction with the main canal. The construction period for the revised layout would be one year compared to three for the original layout. Details are indicated on the technical drawings for the scheme. Since the annual energy productivity is much higher for the original layout (i.e., total head 8.85), it may still be retained as the basis for developing the scheme.

Box 3.4

3.10 *Use of Closed Conduits.* To obviate the need to permanently destroy productive agricultural land near the canal drop sites, the revised designs incorporate the use of closed conduits which would be buried in trenches. Two types were defined: (i) cut and cover conduits which would be cast in situ. The conduits would be lined on all sides and closed at the top with RCC slabs, thereby allowing for their use as pressure conduits; or (ii) precast RCC pipes, 21/ which would be laid either on the surface, or buried. The relative costs of using the two options were evaluated in detail for the Maddur canal drop scheme in Karnataka (Box 3.5).

**Use of Closed Conduits for By-Pass Channels: The Maddur Scheme, Karnataka**

The original proposal was to construct the powerhouse structure immediately downstream of the intake structure, and to use a 300 meter long tailrace which would be an open channel. Since the scheme is located in sugarcane farms, productive agricultural land would be destroyed. Also extensive excavation of rock (about 29,000 m3) would be required to accommodate the horizontal shaft turbine (S-type) with an extended forebay leading up to the powerhouse (see drawings in Annex G).

Several alternative layouts for the Maddur scheme were developed to minimize rock excavation, and to obviate the need to permanently destroy land under cultivation. For the revised layouts, the horizontal shaft turbine was replaced by one with a vertical shaft (elbow type draft tube), and the location of the powerhouse was moved further away from the intake structure to one of three possible locations: (i) the first (Alt I) was at a point some 50 meters downstream of the intake structure; (ii) the second (Alt II) was 100 meters downstream of the intake; and (iii) the third (Alt III) was 200 meters downstream of the intake structure. Instead of the open channel which would require permanent loss of sugarcane growing land, the by-pass channel would consist either of a "cut and cover" conduits which would be cast in situ, or a precast concrete conduit which would be buried in trenches across the field.

The layout for Alt II would require the minimum expenditure for civil works. Five options to convey water from the intake structure to the powerhouse were evaluated. As indicated below, the least cost option involved the use of a 100 meter long "cut and cover" conduit, and a tailrace consisting of a 200 meter long open channel. A similar layout with a precast concrete conduit would be slightly more expensive but probably easier to install, since they could be fabricated within 20 km of the site. The cost of the civil works for the revised layout is estimated to be Rs. 7.3 million compared to Rs. 12.3 million for the original proposal. About Rs. 3.3 million of the reduction in costs would be achieved by avoiding the excavation of some 23,500 m3 of rock, and reducing concreting requirements by 1600 m3).

Estimated Cost of Alternative Water Conveyance Structures for Alt. II
(Rs. million)

| Type of Structure | Intake | Penstock | Powerhouse | Tailrace | Total |
|---|---|---|---|---|---|
| 1.Precast Home Pipe(200 m) | 2.7 | 8.3 | 0.48 | - | 11.48 |
| 2.Cast in Situ Trough (300 m) | 2.7 | 3.9 | 0.48 | - | 7.08 |
| 3.Cast in Situ Trough (100 m) | 2.7 | 1.95 | 0.48 | 1.06 | 6.19 |
| 4.Precast Home Pipe(100 m) | 2.7 | 4.15 | 0.48 | 1.06 | 8.39 |
| 5.Open Tunnel with Embankment | 2.7 | 3.1 | 0.74 | 1.06 | 7.60 |

SOURCE: ESMAP estimates

Box 3.5

21/ The pipes would be buried in channels. Excavated materials would be used as backfill for the pipes.

## B. Design of Electrical Systems

3.11 The original set of *"Single-Line Diagrams"* for electrical switching, protection, and control incorporate a large number of redundant instruments. Hence the main thrust of the study has been to simplify those proposals with a view to reducing both capital and maintenance costs (e.g., eliminate use of battery powered controls). A set of eighteen standardized single-line diagrams were developed for the fifty schemes. The complete set of detailed diagrams on the layout of the electrical systems are presented for each of the fifty schemes in the Technical Supplement. Further simplifications to reduce costs may be appropriate; for example, load break switches instead of circuit breakers could be installed between the generators and the transformers.

3.12 Similar work was done to streamline the protection systems for the induction generators and transformers. Three sets of standard protection schemes were prepared for the schemes: (i) *Category "A"* for schemes comprising units of 350 kW and 650 kW capacities; (ii) *Category "B"* for schemes with unit capacities of between 1000-2500 kW; and (iii) *Category "C"* for schemes with units of capacity greater than 3500 kW. The standardized protection arrangements also are presented in the drawings below.

## C. Grid-Tie Arrangements

3.13 The approach used was to select grid-tie arrangements which would connect each mini-hydro scheme directly by 11 kV lines to a nearby 11/33 kV sub-station. Considering energy losses, that arrangement may not always be the least cost option. There is the need for more detailed analysis to determine the grid-tie arrangement that would minimize energy losses; detailed analysis would need to be made of line losses, voltage drops during peak load periods, etc. In some cases (*Box 3.6*), the preferred arrangement may require the use of higher voltage lines (i.e., 33 kV to 110 kV).

**Alternative Grid-Tie Arrangements**

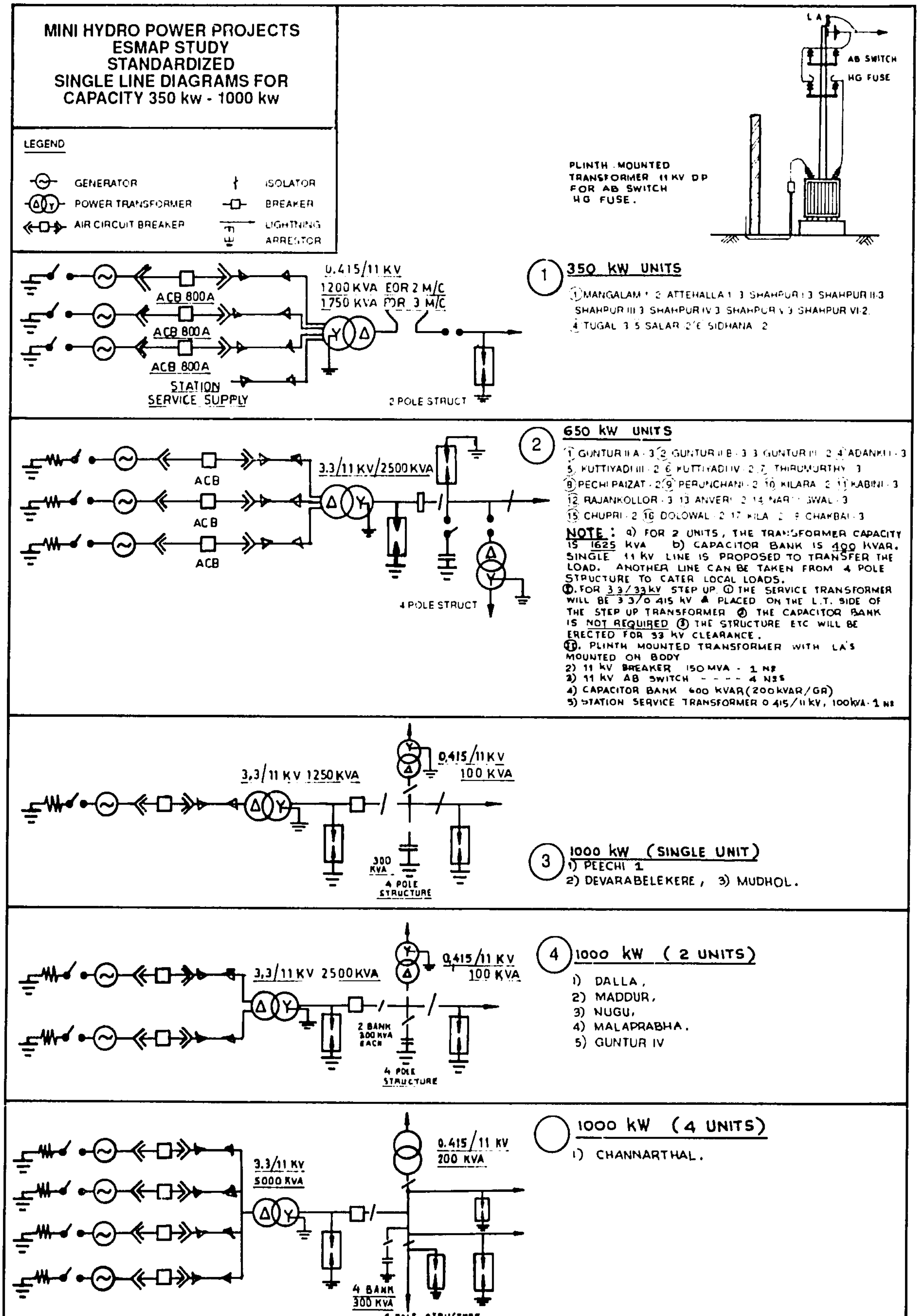
Lower Bhavani Scheme: The powerhouse for the scheme would be located adjacent to the powerhouse of the recently commissioned 8 MW plant. The existing powerhouse is connected by a three circuit 11 kV line (each 6 km. long) to the nearby 110/11 kV substation at Bhavanisagar. Two alternative grid-tie arrangements for the proposed scheme are: (i) use of three new circuits of 11 kV lines to connect the scheme to the Bhavanisagar sub-station; (ii) linking the two powerhouses by a 200 meter long line (11 kV), installing a step-up transformer (11/110 kV) for the combined output (8 + 7 MW), and connecting by 110 kV to the Bhavanisagar sub-station. The extra cost of installing the 110 kV line for the second alternative could be offset by the costs of acquiring wayleaves for the additional 11 kV lines plus the energy losses under the first alternative. Hence further studies need to be conducted at the time of detailed design.

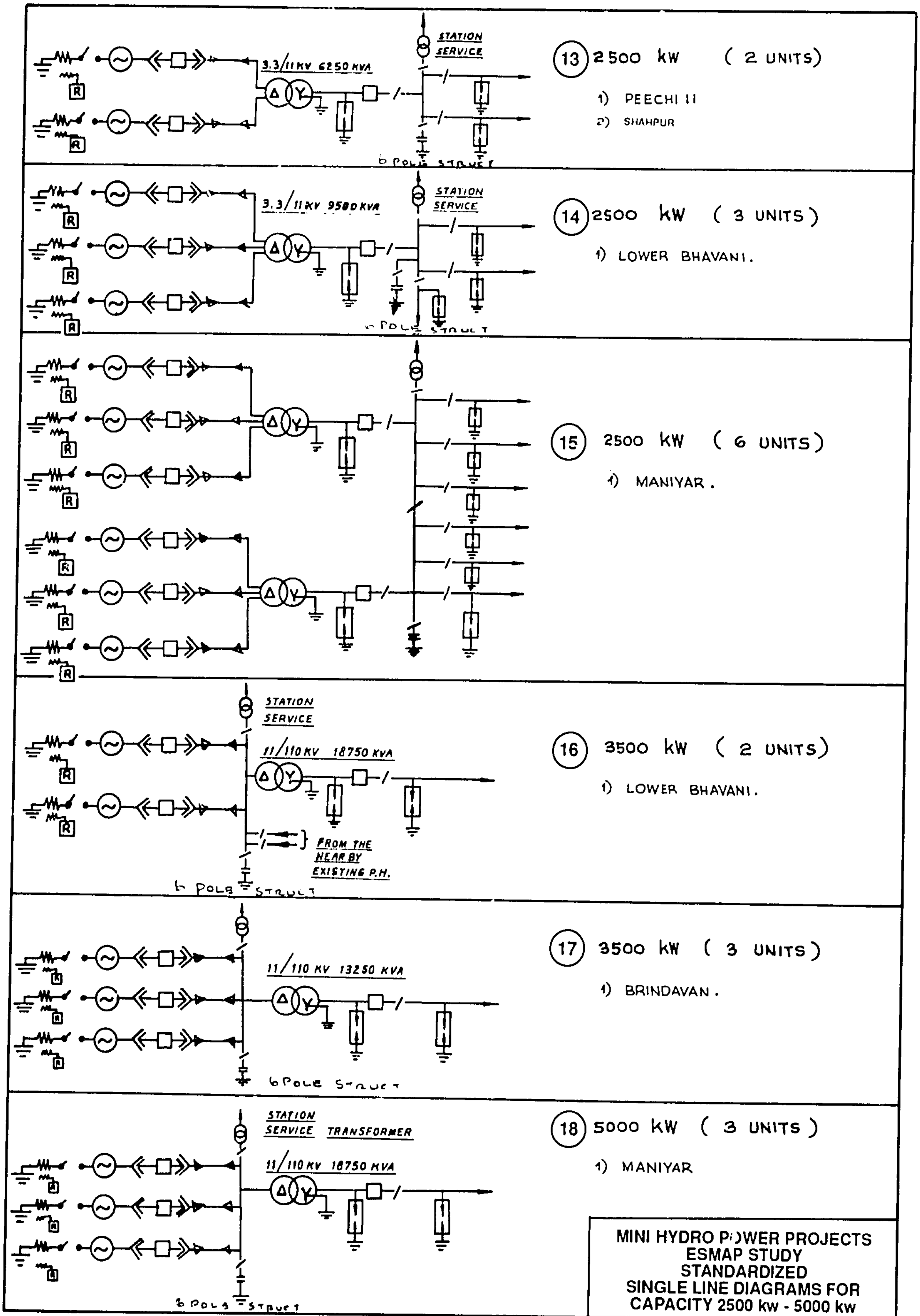
Brindavan Dam Scheme: The nearest sub-station is located at Belgola (110/11 kV) which is about 10 km from the powerhouse. Four circuits of 11 kV lines would be required to transfer the energy from the 10.5 MW scheme. In addition, the capacity of the Belgola sub-station would have to be expanded. The alternative would be to add a 11/110 kV step-up transformer at the powerhouse, and to connect the scheme to the Belgola sub-station with a 110 kV line. The reduction in costs due to energy losses may more than offset the increased cost of using the 110 kV line.

Maddur Canal Drop Scheme: The nearest sub-station to the powerhouse for the Maddur scheme is located 10 km away at Mandya. The load in the immediate vicinity of the scheme is slightly higher than 2 MW, the installed capacity at Maddur. By feeding the energy from the scheme directly into the local distribution lines, costs as well as energy losses would be minimized.

Guntur Branch Canal Cluster: The cluster comprises five schemes (total capacity about 11 MW) along the canal in the Guntur District. The nearest sub-station, located near Narasaraopet which is about 16 km away from that stretch of the canal handles 11/33 kV. Energy losses are likely to be high if the schemes are connected by 11 kV lines to the sub-station. The alternative worth further evaluation would be to link all the powerhouses at one point, install a transformer to step up from 11 kV to 33 kV, and to transfer the energy at 33 kV to the sub-station.

Box 3.6


MINI HYDRO POWER PROJECTS
ESMAP STUDY
STANDARDIZED
SINGLE LINE DIAGRAMS FOR
CAPACITY 350 kw - 1000 kw
LEGEND
GENERATOR
POWER TRANSFORMER
AIR CIRCUIT BREAKER
ISOLATOR
BREAKER
LIGHTNING ARRESTOR
LA
AB SWITCH
HG FUSE
PLINTH MOUNTED TRANSFORMER 11 KV DP FOR AB SWITCH HG FUSE.
0.415/11 KV
1200 KVA FOR 2 M/C
1750 KVA FOR 3 M/C
ACB 800A
ACB 800A
ACB 800A
STATION SERVICE SUPPLY
2 POLE STRUCT
1 350 KW UNITS
1 MANGALAM 2 ATTEHALLA 1 3 SHAHPUR I 3 SHAHPUR II-3
SHAHPUR III 3 SHAHPUR IV 3 SHAHPUR V 3 SHAHPUR VI-2.
4 TUGAL 3 5 SALAR 2 6 SIDHANA 2
3.3/11 KV/2500 KVA
ACB
ACB
ACB
4 POLE STRUCT
2 650 kW UNITS
1 GUNTUR II A - 3 2 GUNTUR II B - 3 3 GUNTUR III 2 4 ADANKI - 3
5 KUTTIYADI III - 2 6 KUTTIYADI IV - 2 7 THIRUMURTHY 3
8 PECHI PAIZAT - 2 9 PERUNCHANI - 2 10 KILARA 2 11 KABINI - 3
12 RAJANKOLLOR - 3 13 ANVERI 2
15 CHUPRI - 2 16 DOLOWAL - 2 17 KILA
NOTE : a) FOR 2 UNITS, THE TRANSFORMER CAPACITY IS 1625 KVA b) CAPACITOR BANK IS 400 KVAR. SINGLE 11 KV LINE IS PROPOSED TO TRANSFER THE LOAD. ANOTHER LINE CAN BE TAKEN FROM 4 POLE STRUCTURE TO CATER LOCAL LOADS.
II. FOR 3.3/33 KV STEP UP. 1 THE SERVICE TRANSFORMER WILL BE 3.3/0.415 KV & PLACED ON THE L.T. SIDE OF THE STEP UP TRANSFORMER 2 THE CAPACITOR BANK IS NOT REQUIRED 3 THE STRUCTURE ETC WILL BE ERECTED FOR 33 KV CLEARANCE.
III. PLINTH MOUNTED TRANSFORMER WITH LA'S MOUNTED ON BODY
2) 11 kV BREAKER 150 MVA - 1 No
3) 11 kV AB SWITCH - - - - 4 Nos
4) CAPACITOR BANK 600 KVAR (200 kVAR/GR)
5) STATION SERVICE TRANSFORMER 0.415/11 kV, 100 kVA - 1 No
3.3/11 KV 1250 KVA
0.415/11 KV
100 KVA
300 KVA
4 POLE STRUCTURE
3 1000 kW (SINGLE UNIT)
1) PEECHI 1
2) DEVARABELEKERE, 3) MUDHOL.
3.3/11 KV 2500 KVA
0.415/11 KV
100 KVA
2 BANK 300 KVA EACH
4 POLE STRUCTURE
4 1000 kW (2 UNITS)
1) DALLA,
2) MADDUR,
3) NUGU,
4) MALAPRABHA.
5) GUNTUR IV
3.3/11 KV
5000 KVA
0.415/11 KV
200 KVA
4 BANK
300 KVA
6 POLE STRUCTURE
1000 kW (4 UNITS)
1) CHANNARTHAL.




SHEET 3 OF 3

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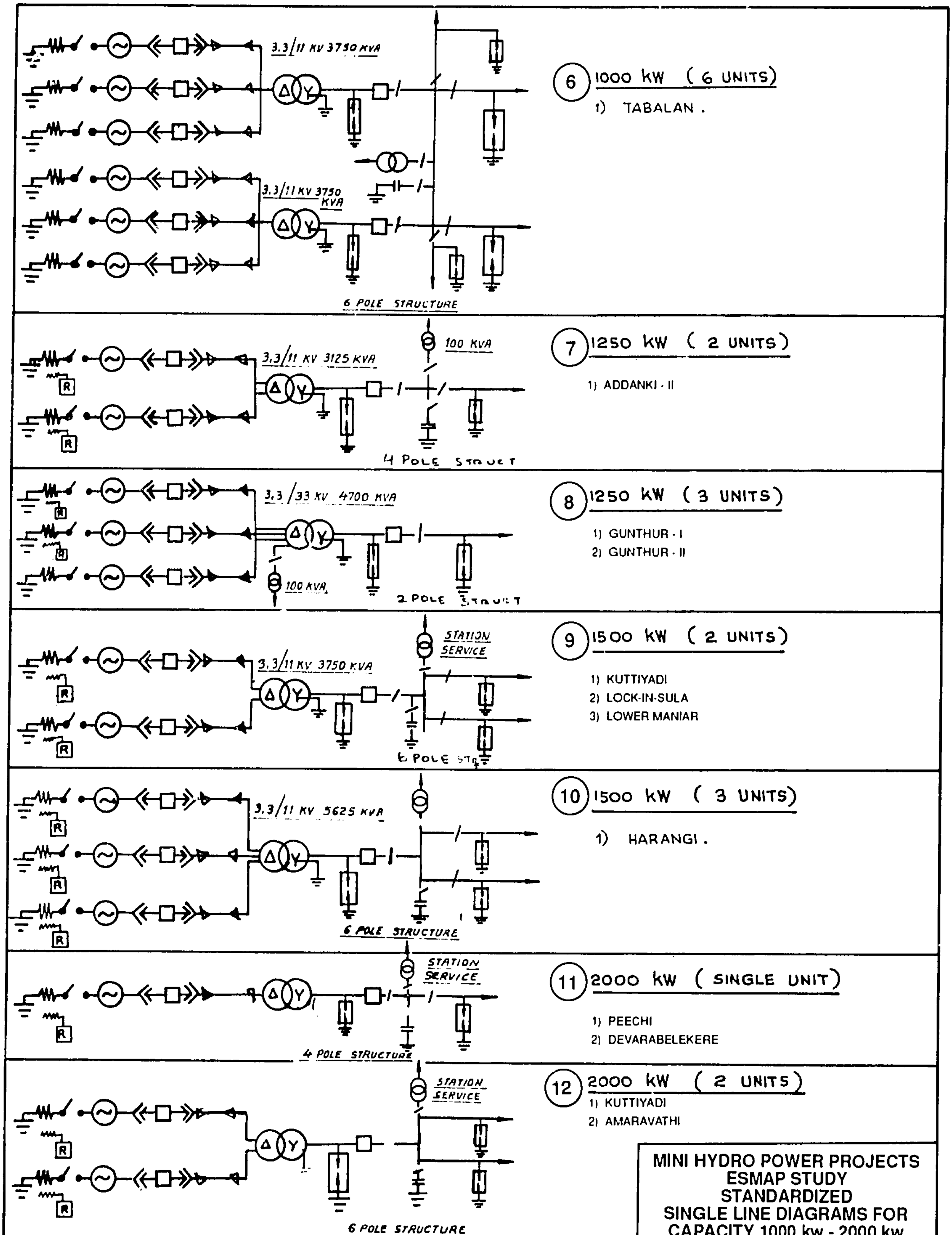
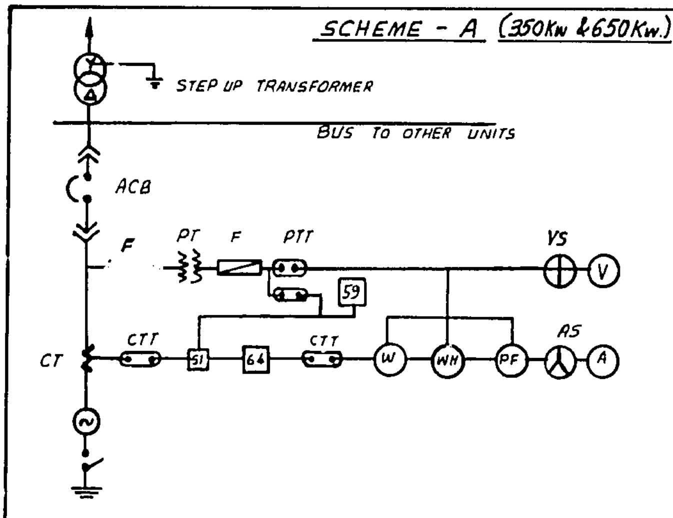
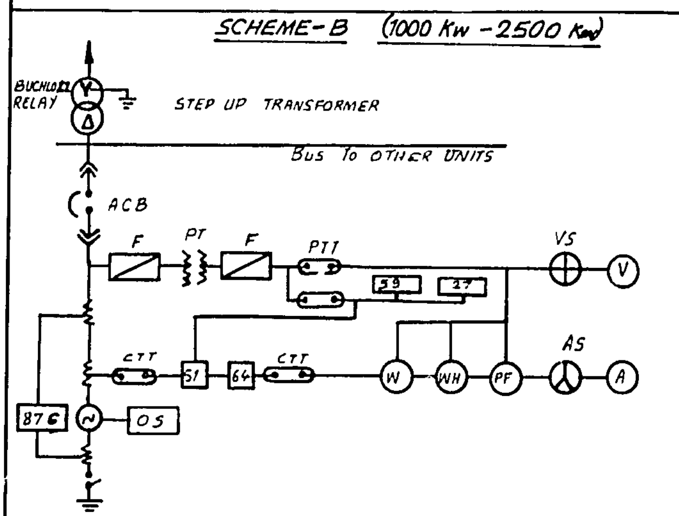
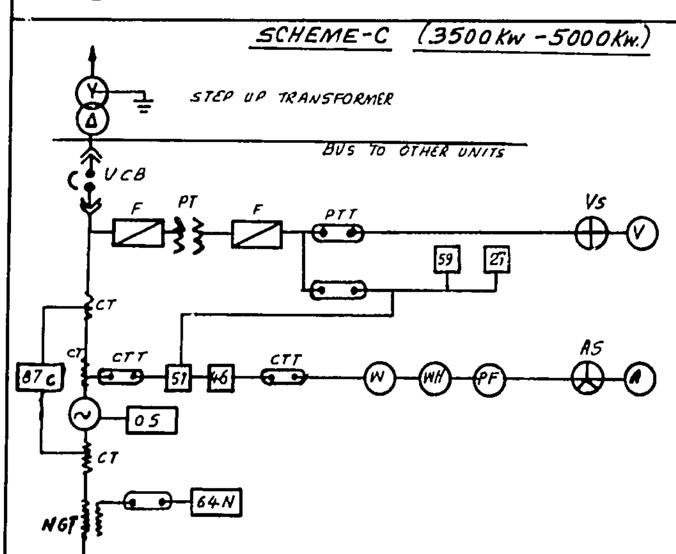



SHEET 2 OF 3

sads/w48595( 2 )




## NOTES

THE PROTECTION SCHEMES HAVE BEEN GROUPED INTO THREE CATEGORIES.

CATEGORY 'A' 350 KW AND 650 KW CAPACITY

CATEGORY 'B' 1000 KW 1250KW 1500 KW & 2500 KW CAPACITY

CATEGORY 'C' 3500 KW AND 5000 KW CAPACITY

THE DETAILS ILLUSTRATED IN FIGURES A B & C FORM MINIMUM REQUIREMENTS FOR SATISFACTORY PROTECTION OF GENERATORS AND STEP UP TRANSFORMERS. HOWEVER ADDITIONAL DETAILS OR MODIFICATIONS CAN BE INCORPORATED AS PER THE PRACTICE OF STATE ELECTRICITY BOARDS. THE MAXIMUM COST OF THE CATEGORIES MAY NOT EXCEED Rs 150,000 (8000 $) HENCE PROVISION OF ADDITIONAL RELAYS IS POSSIBLE WITHOUT SIGNIFICANT CHANGE IN OVERALL COSTS.

## LEGEND

CT — CURRENT TRANSFORMER

PT — POTENTIAL TRANSFORMER

CTT — C.T TERMINAL

PTT — PT TERMINAL

F — FUSE

05 — OVER SPEED RELAY

51 — VOLTAGE RESTRAINED OVER CURRENT RELAY

64 — IDMT EARTH FAULT RELAY

46 — PHASE UNBALANCE CURRENT RELAY

59 — OVER VOLTAGE RELAY

27 — UNDER VOLTAGE RELAY

A — AMMETER

AS — AMMETER SWITCH

VS — VOLTMETER SWITCH

V — VOLTMETER

W — WATTMETER

WH — WATT HOUR METER

PF — POWER FACTOR METER

ACB — AIR CIRCUIT BREAKER

VCB — VACUUM CIRCUIT BREAKER

MINI HYDRO POWER PROJECT
ESMAP STUDY
PROTECTION SCHEME FOR STANDARDISED UNITS

## D. Capital Cost Estimates

3.13 The base costs of each scheme (i.e., in financial terms) were computed in 1990 prices (*Annex D*) according to the following categories:

(a) civil structures, comprising gates, intake, channel/penstock, powerhouse, tailrace;

(b) hydro-mechanical equipment, comprising the turbine and its auxiliaries, and the inlet valve;

(c) electrical equipment, comprising the induction generator and its auxiliaries, the transformers, capacitors, breakers, switches, etc.;

(d) grid-tie materials and labor costs, especially for the transmission line.

3.14 The base costs were entered into the World Bank's PCCOSTAB software as domestic prices. The costs were increased to incorporate: (i) the costs of installing the main items of equipment (i.e., turbine and auxiliaries, generator and auxiliaries, etc.), based on relationships indicated in *Annex D*; (ii) physical contingencies, at 5% of base costs; (iii) price contingencies to reflect inflation; and (iv) taxes and duties. Price contingencies were derived assuming that the annual inflation rate (local costs) would vary from 8.4% in 1991, 7.0% during 1992-93, and decline to 6.6% by 1994. It also was assumed that taxes on the main cost items would be 3% for civil works, 6% for electro-mechanical equipment, and 3% for electrical systems. The estimates for all the schemes are shown in the *Tables 3.2 to 3.4* below.

**UNIT COSTS OF STANDARDIZED TURBINES AND GENERATORS**

| Turbine Runner Dia. (m) | No. of Schemes | No. of Units | Unit Cost (Rs.millions)a/ |
|---|---|---|---|
| 2800 | 2 | 10 | 9.2 |
| 2500 | 9 | 20 | 8.0 |
| 2000 | 9 | 25 | 6.0 |
| 1400 | 14 | 28 | 4.0 |
| 1250 | 15 | 32 | 3.0 |
| 1000 | 3 | 6 | 2.5 |
| Totals | 52 | 121 | |

| Generator Capacity (kW) | No. of Schemes | No. of Units | Unit Cost (Rs.millions)a/ |
|---|---|---|---|
| 3500 | 2 | 5 | 7.5 |
| 2500 | 3 | 10 | 4.0 |
| 2000 | 1 | 2 | 3.0 |
| 1500 | 5 | 10 | 2.5 |
| 1250 | 4 | 10 | 2.0 |
| 1000 | 8 | 20 | 1.5 |
| 650 | 18 | 40 | 1.0 |
| 350 | 11 | 24 | 0.8 |
| | 52 | 121 | |

a/ units cost data in Annex D
Source: ESMAP estimates

Table 3.1

3.15 The selection of fixed vane/fixed blade turbines instead of full kaplan turbines, induction generators instead of synchronous generators, elimination of governor systems, etc., as well as the selection of materials for turbine fabrication are all critical factors to minimize the capital cost of schemes. For example, several of the original specifications prepared by the SEBs were based unnecessarily on the use of stainless steel to fabricate the turbines (i.e., runners, blade, runner chamber); the costs would be reduced considerably by using aluminium bronze. As shown in the example based on the proforma price quotations for turbine specifications for the original and revised designs of a prospective scheme (Box 3.7), the scope for reducing costs is considerable.

**Comparative Analysis of Cost Estimates for Turbines:**
**The Guntur BC 1 Scheme, Andhra Pradesh**

The original design was to install 3x1200 kW turbine-generator units; it had been specified that the turbine would be a full kaplan with tubular downstream elbow (S-type) configuration. The specifications for main components were: (i) the turbine would have four blades made of cast stainless steel, a carbon steel hub, and the runner diameter would be 1850 mm.; (ii) the runner chamber would be split horizontally and also fabricated with stainless steel; and (iii) the draft tube cone and bend would be fabricated from steelplate. In addition, the turbine would be equipped with an oil pumping unit and an oil head for blade control, a draft tube dewatering system, and a gearbox (240/750 rpm.). The proforma price quotation obtained from a local manufacturer in December, 1990 indicated that the cost would be about Rs. 13.7 million, including the gearbox.

The revised standardized design would require the installation of 3x1250 kW units. The units would be fixed vane/fixed blade turbines with upstream elbow configuration, and would be fabricated in aluminium bronze. The runner diameter would be 2000 mm.; a gearbox (214/600 rpm) would also be provided. Based on proforma price quotations obtained from manufacturers, the cost of the turbine, gearbox, and auxiliaries would be about Rs. 6.5 million.

In addition to the simpler configuration of the turbine, the reduction in costs can be attributed to: (i) substitution of stainless steel with aluminium bronze for fabrication of main turbine components; (ii) elimination of oil pumping unit and oil head which was necessary for

Box 3.7

**CAPITAL COST ESTIMATES SCHEMES ASSOCIATED WITH DAMS/BARRAGES, AND WEIRS**

| State/Location | | Civil | (Rs.millions) a/ Hyd-Mech. | Elect. | Grid-Tie | Total Costs |
|---|---|---|---|---|---|---|
| ANDHRA PRADESH | | | | | | |
| 1. | Lower Manair | 10.3 | 14.8 | 7.8 | 0.2 | 33.1 |
| KARNATAKA | | | | | | |
| 1. | Mudhol Dam | 3.5 | 3.7 | 3.5 | 0.8 | 11.4 |
| 2. | Malaprabha Dam | 4.9 | 9.9 | 5.4 | 0.2 | 20.4 |
| 3. | Deverebelerkere | 9.9 | 4.9 | 3.3 | 0.3 | 18.4 |
| 4. | Attehalla Weir | 3.8 | 3.6 | 1.8 | 0.5 | 9.7 |
| 5. | Brindavan Dam | 4.6 | 29.4 | 30.1 | 2.9 | 67.0 |
| 6. | Nugu Dam | 4.6 | 9.5 | 5.2 | 1.8 | 20.9 |
| 7. | Harangi Dam | 4.5 | 14.2 | 10.8 | 1.5 | 31.0 |
| 8. | Kabini Dam | 4.5 | 14.2 | 5.1 | 1.2 | 25.0 |
| KERALA | | | | | | |
| 1. | Peechi Dam I | 2.2 | 3.6 | 3.3 | 3.8 | 12.9 |
| | Peechi Dam II | 7.1 | 10.5 | 11.7 | 4.8 | 34.1 |
| 2. | Kuttiyadi I | 5.8 | 10.1 | 7.7 | 0.1 | 23.7 |
| | Kuttiyadi II | 2.2 | 9.5 | 3.9 | 0.1 | 15.7 |
| | Kuttiyadi III | 2.5 | 9.5 | 3.8 | 0.1 | 15.9 |
| 3. | Maniyar Barrage | 14.1 | 43.9 | 34.1 | 1.9 | 94.0 |
| 4. | Mangalam Dam | 2.4 | 0.5 | 2.3 | 1.2 | 6.3 |
| TAMIL NADU | | | | | | |
| 1. | Lower Bhavani | 4.6 | 19.6 | 22.1 | 1.2 | 47.4 |
| 2. | Thirumurthy | 4.6 | 7.2 | 5.3 | 3.1 | 20.2 |
| 3. | Amaravathy | 3.8 | 9.5 | 9.3 | 2.4 | 24.9 |
| 4. | Aliyar | 4.2 | 6.3 | 7.1 | 0.1 | 17.7 |
| 5. | Sathanur | 7.5 | 9.5 | 12.0 | 2.9 | 31.9 |
| 6. | Peechiparai | 4.9 | 9.9 | 4.2 | 0.1 | 19.1 |
| 7. | Perunchani | 4.9 | 7.5 | 4.3 | 2.2 | 18.9 |

SOURCE: ESMAP estimates

Table 3.2

**CAPITAL COST ESTIMATES SCHEMES ASSOCIATED WITH CANAL DROPS**

| State/Location | | Civil | Hyd-Mech | Elect. | Grid-Tie | Total Costs |
|---|---|---|---|---|---|---|
| | | (Rs.millions) | | | | |
| **ANDHRA PRADESH** | | | | | | |
| Guntur Branch Canal Cluster | | | | | | |
| 1.1 | GBC I (M0-0-550) | 8.3 | 21.9 | 7.4 | 0.9 | 38.5 |
| 1.2 | GBC II (M2-4-00) | 14.0 | 20.5 | 6.1 | 2.3 | 42.9 |
| 1.3 | GBC III (M5-2-550) | 5.9 | 14.6 | 4.1 | 0.2 | 24.9 |
| 1.4 | GBC IV (M9-1-550) | 8.5 | 14.6 | 5.3 | 0.2 | 28.7 |
| 1. | GBC Cluster Total | 34.7 | 95.1 | 27.2 | 1.9 | 158.9 |
| Adanki Branch Canal Cluster | | | | | | |
| 2.1 | ABC I (M17-4-0) | 6.5 | 14.6 | 3.9 | 4.4 | 29.5 |
| 2.2 | ABC II (M18-3-220) | 6.5 | 14.6 | 6.5 | 1.1 | 28.7 |
| | ABC Cluster Total | 13.0 | 29.2 | 10.4 | 5.5 | 58.2 |
| 3. | Lock-in-Sula | 11.6 | 15.2 | 8.2 | 1.9 | 37.1 |
| **KARNATAKA** | | | | | | |
| 1. Shahpur Branch Canal Cluster | | | | | | |
| 1.1 | SBC 1 | 3.8 | 14.6 | 3.8 | 0.7 | 22.9 |
| 1.2 | SBC 2 | 8.7 | 11.1 | 4.1 | 0.7 | 24.6 |
| 1.3 | SBC 3 | 9.3 | 11.1 | 3.8 | 0.7 | 24.9 |
| 1.4 | SBC 4 | 4.8 | 11.1 | 3.8 | 0.7 | 20.5 |
| 1.5 | SBC 5 | 3.3 | 11.1 | 3.8 | 0.7 | 19.1 |
| 1.6 | SBC 6 | 4.3 | 3.7 | 1.9 | 0.7 | 10.6 |
| | SBC Cluster Total | 34.4 | 62.9 | 21.2 | 4.2 | 122.7 |
| 2. | Rajankollar BC | 5.8 | 11.1 | 5.5 | 1.5 | 24.0 |
| 3. | Anveri BC | 4.6 | 7.4 | 4.0 | 0.6 | 16.7 |
| 4. | Maddur Scheme | 8.4 | 7.2 | 5.3 | 1.2 | 22.1 |
| 5. | Kilara Scheme | 11.8 | 9.4 | 6.1 | 0.7 | 28.0 |
| **PUNJAB** | | | | | | |
| Bhatinda Branch Canal Cluster | | | | | | |
| 1. | Chak Bhai | 3.6 | 19.1 | 4.0 | 0.7 | 27.4 |
| 2. | Sidhana | 1.7 | 7.2 | 1.8 | 0.6 | 11.5 |
| Kotla Branch Canal Cluster | | | | | | |
| 3. | Dolowal | 3.9 | 19.6 | 4.0 | 0.4 | 27.9 |
| 4. | Babanpur | 3.9 | 19.6 | 4.0 | 0.4 | 27.9 |
| 5. | Killa | 3.3 | 19.6 | 4.0 | 0.4 | 27.2 |
| 6. | Salar | 2.6 | 14.6 | 3.0 | 0.3 | 20.6 |
| Abohar Branch Canal Cluster | | | | | | |
| 7. | Narangwal | 3.6 | 29.1 | 5.2 | 0.2 | 38.1 |
| 8. | Dalla | 5.3 | 19.6 | 5.2 | 0.2 | 30.3 |
| 9. | Tugal | 3.6 | 21.9 | 3.7 | 0.4 | 29.8 |
| 10. | Chupki | 4.2 | 19.6 | 4.0 | 0.4 | 28.2 |
| Bhakra (Nangal Hydel) Canal | | | | | | |
| 11. | Chanarthal | 11.6 | 46.8 | 9.5 | 0.6 | 68.7 |
| 12. | Thablan | 13.9 | 70.9 | 14.5 | 6.5 | 105.9 |

SOURCE: ESMAP estimates.

Table 3.3

# IV. ECONOMIC EVALUATION OF PROSPECTIVE SCHEMES

## A. Introduction

4.1 The economic viability of the irrigation based mini-hydro schemes was assessed in terms of their cost competitiveness relative to conventional sources of generation in the grid (i.e., from the least cost system development plan). Since India's power systems are planned and operated on a regional basis, the cost of generation from the proposed irrigation based mini-hydro schemes in the States of Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu were compared to the marginal costs of generation in the Southern Regional Grid, while those in Punjab were assessed in the context of the Northern Regional Grid. To measure the economic value of the net benefits from the proposed schemes, the economic internal rate of return and the net present value for each scheme at a 12% discount rate were derived. 22/

## B. Economic Value of Benefits and Costs

*Economic Value of Benefits*

4.3 Given the large sizes of the southern and northern regional grid systems, 23/ it is clear that none of the irrigation based mini-hydro schemes would be large enough to significantly affect the system development plans of the grids (i.e., requiring a deferral of capacity expansion projects and/or a re-optimization of the use of existing thermal stations). Rather, because the power supply situation in both regional grids is energy constrained, 24/ the principal role of the irrigation based mini-hydro schemes would be to alleviate localized energy deficits by providing energy support to improve the quality of service in remote portions of the grid and to displace higher cost energy supplies from thermal power stations. Furthermore, the additional output from the irrigation based mini-hydro schemes would reduce the extent of standby diesel auto-generation by industrial and commercial establishments.

4.4 *Avoided Costs of Energy Supply.* The economic value of the benefits of the mini-hydro schemes were derived in terms of the avoided costs of energy supply at the 33 kV level from the regional power grids. Specifically, during off-peak hours of service, the avoided costs of energy supply from the grid consists of the fuel costs plus variable operating and maintenance expenses of the less efficient or marginal stations in service (i.e, the short-run marginal costs of generation). These can reach as high as Rs. 0.65/kWh at the generation busbar in the Southern Regional Grid (e.g., TNEB's Ennore Station), and up to Rs. 0.75/kWh in the Northern Regional Grid. However, the less efficient stations tend also to lack the operational flexibility required to curtail their

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22/ The COSTBEN computer program of the World Bank was used to perform the economic analysis.

23/ The installed capacity is of the order of 12500 MW in the Southern Regional Grid, and about 14500 MW in the Northern Regional Grid.

24/ The peak energy demand in the Southern Regional Grid is of the order of 180 GWh/day, but the supply capability is only about 160 GWh/day. In the Northern Regional Grid, the peak energy demand exceeds 190 GWh/day but the energy supply capability is only 180 GWh/day.

operation during periods of reduced system loading· ·herefore an average of the avoided costs of energy supply from the grids (Rs. 0.55-0.60 per kWh) was used to set the economic value of the benefits from the irrigation based mini-hydro schemes. Since the irrigation based mini-hydro schemes would be tied to the grid at the 11/33 kV sub-stations, the energy would be generated much closer to the point of electricity use, and therefore the savings from the transmission and distribution (T&D)losses that would be avoided is significant. Accordingly, the avoided cost of energy supply from the grid was adjusted upwards (assuming 15% T&D losses) to arrive at economic value of benefits in the range of Rs. 0.63-0.69 per kWh.

4.5 During the periods of daily peak demand (about 5 hours), power outages are widespread and large numbers of industrial and commercial consumers resort to the use of standby diesel generators. Under those circumstances, the avoided costs of energy supply would reflect the variable costs of auto-generation from stand-by diesel units operated by commercial (Rs. 1.31 per kWH) and Industrial (Rs. 1.16 per kWh) establishments. Combining the avoided costs of energy supply during the off-peak and peak periods, the composite value of the energy produced by the proposed irrigation based mini-hydro schemes was estimated to be in the order of Rs. 0.80 per kWh.

4.6 *Capacity Credit for Schemes.* The high degree of congruity between the seasonal discharge of irrigation water and the seasonal variations in peak load within both regional grids, suggests that a capacity credit should be considered as an additional benefit of the proposed irrigation based mini-hydro schemes. However, given that the irrigation discharges are restricted to between nine to ten months each year, and that the SEBs do not have effective control of water flows even during those months of sustained operations, energy generation levels and capacity availability were considered to be "non-firm". Accordingly, capacity credits attributed to the proposed schemes were not quantified for the purposes of this evaluation which lends a conservative bias to the economic value of the benefits. It is expected, however, that during detailed design of mini-hydro investment programs in each state, a more comprehensive assessment of the benefits would be made to incorporate capacity credits at a justifiable level.

*Economic Capital Costs*

4.7 To arrive at the economic capital costs associated with the irrigation based mini-hydro schemes, the domestic component of the capital costs for equipment and civil works (Tables 3.3 and 3.4) were adjusted by applying a standard conversion factor of 0.8, and removing taxes and duties. Annual operating and maintenance costs were taken to be equivalent to 2% of capital costs over the 25 year economic life of each scheme. The economic capital costs per installed kW for each scheme is presented in Tables 4.2 and 4.3 below.

## C. Discounted Cash Flow Analysis

4.8 The cashflow streams of the costs and (energy) benefits for the prospective mini-hydro schemes were developed both for each schemes as follows. The entire capital costs for each scheme would be disbursed during the first year of construction hence interest during construction would be charged for one year at a rate equal to the opportunity cost of capital (12%), and added to the costs of each scheme. Benefits (i.e., energy production) would begin to accrue after 18 months of the start of work on each scheme. To obtain the net present value (NPV) of each scheme, the cash flow streams of the respective costs and benefits were also discounted at 12% per annum over the 25 year economic life of each plant.

4.9 The EIRR for the dam based schemes were in the range of 14-66% (Table 4.21), and for schemes located on canal drops, 12-29% (*Table 4.2*). The NPV at 12% discount rate, the investment per unit of installed capacity (i.e., in economic prices), and the *annual energy productivity* of each scheme are summarized also in same tables.

**ECONOMIC EVALUATION OF DAM BASED MINI-HYDRO SCHEMES**

| SCHEME NAME | INVESTMENT (Rs./kW) | ENERGY PROD. (kWh pa/100 Rs.) | EIRR (%) | NPV @12% (Rs.million) |
|---|---|---|---|---|
| **KARNATAKA** | | | | |
| Brindavan | 5592 | 117.5 | 65.7 | 428.7 |
| Harangi | 5942 | 51.8 | 30.8 | 103.0 |
| Kabini | 10972 | 29.8 | 17.5 | 57.8 |
| Nugu | 8827 | 32.2 | 19.1 | 50.0 |
| Deverebelerkere | 5204 | 58.9 | 42.1 | 61.0 |
| Mudhol | 8915 | 58.3 | 34.5 | 33.2 |
| Malaprabha | 8228 | 44.2 | 26.3 | 50.4 |
| **TAMIL NADU** | | | | |
| Lower Bhavani | 5891 | 58.3 | 34.6 | 172.6 |
| Thirumurthy | 9602 | 45.9 | 30.4 | 64.4 |
| Amaravathy | 8482 | 46.1 | 27.4 | 75.3 |
| Aliyar | 11642 | 61.6 | 38.5 | 57.7 |
| Sathanur | 5362 | 75.7 | 44.0 | 136.9 |
| Peechiparai | 11724 | 33.2 | 19.7 | 43.9 |
| Perunchani | 12962 | 26.5 | 21.3 | 39.0 |
| **ANDHRA PRADESH** | | | | |
| Lower Manair | 9297 | 71.3 | 41.4 | 136.5 |
| **KERALA** | | | | |
| Peechi | 7836 | 73.2 | 41.2 | 210.0 |
| Mangalam | 14140 | 20.4 | 13.5 | 10.6 |
| Kuttiyadi Cascade | 9130 | 55.7 | 40.7 | 199.5 |
| Maniyar | 5426 | 71.4 | 41.1 | 394.9 |

SOURCE: ESMAP estimates

Table 4.1

**ECONOMIC EVALUATION OF MINI-HYDRO SCHEMES AT CANAL DROPS AND WEIRS**

| SCHEME NAME | INVESTMENT (Rs./kW) | ENERGY PROD. (kWh pa/100 Rs.) | EIRR (%) | NPV @12% (Rs.million) |
|---|---|---|---|---|
| ANDHRA PRADESH | | | | |
| Guntur BC Cluster | 12395 | 44.3 | 22.9 | 429.8 |
| Adanki BC Cluster | 12891 | 21.3 | 14.2 | 119.4 |
| Lock-In-Sula | 9807 | 56.0 | 29.2 | 97.0 |
| PUNJAB | | | | |
| Bhatinda BC Cluster | 14702 | 38.5 | 20.4 | 91.5 |
| Kotla BC Cluster | 19478 | 27.9 | 14.7 | 222.1 |
| Abohar BC Cluster | 17396 | 29.6 | 18.6 | 305.2 |
| Bhakra | 14406 | 51.0 | 19.7 | 368.5 |
| KARNATAKA | | | | |
| Shahpur BC Cluster | 16981 | 21.6 | 13.3 | 206.8 |
| Attehala Weir | 22560 | 28.6 | 12.2 | 22.7 |
| Maddur | 10089 | 44.4 | 29.1 | 67.8 |
| Kilara | 16199 | 26.5 | 13.9 | 55.2 |
| Anveri | 10245 | 42.8 | 29.3 | 44.0 |
| Rajankollur | 9848 | 30.3 | 20.3 | 49.8 |

SOURCE: ESMAP estimates

Table 4.2

# V. FINANCIAL EVALUATION

## A. Introduction

5.1 The financial attractiveness of the proposed mini-hydro schemes was evaluated from two perspectives. The first perspective is that the SEBs which may have the responsibility of implementing several of the schemes covered by this study. The aim of the evaluation was: (i) to establish the minimum cashflow requirements to ensure full recovery by the SEBs of the costs associated with debt servicing, and the operation and maintenance of the irrigation based mini-hydro programs, assuming that each SEB would establish "*cost centers*" to manage and monitor accounts for all phases of the respective mini-hydro programs. Since the State governments are encouraging the private sector to invest in developing irrigation based mini-hydro prospects, the second perspective for the financial analysis was that of evaluating the attractiveness of private captive generation with irrigation based mini-hydro. It was necessary to determine the rate of return on equity for private development of two schemes in this study, using as an example, the conditions stipulated in recent lease agreements in Karnataka.

## B. Cost Recovery Requirements for SEBs

5.2 *Rationale for Mini-Hydro "Cost Centers".* One of the goals for the follow-up to this study is to demonstrate that, despite the persisting financial problems of the SEBs, the schemes in each state could be executed and managed by SEBs in a manner that would ensure economic cost recovery. During the study, discussions were held with senior officials at the state level to define a suitable framework for involving the SEBs in the implementation the mini-hydro schemes. The discussions centered primarily on the need to streamline project management arrangements in each state, and to introduce an effective system for monitoring and controlling the cost-effectiveness of mini-hydro schemes; the overall aim, despite the persisting financial problems of the SEBs, was to ensure that the mini-hydro programs in each state would be managed by SEBs in a manner that would ensure economic cost recovery. The consensus reached was that it would be feasible to set up mini-hydro "cost centers" in the respective SEBs to record, control, and monitor all costs associated with the mini-hydro program, and to track progress in constructing and operating the schemes to achieve economic cost recovery and self-sufficiency. Accordingly, one objective for the financial analyses was to determine the "profitability" of the proposed SEB mini-hydro "*cost centers*".

5.3 *Financing for SEB "Cost Centers".* So far, the bulk of the funds used for the development of the initial batch of irrigation based mini-hydro schemes has been mobilized from the state government level. The GOI provided some financial support to the state government initiatives and extended some credits and grants through agencies such as the DNES, the REC, and the Power Finance Corporation (PFC) respectively. 23/ For the Eight Plan, the GOI plans a substantial increase in its direct financial support to the states for irrigation based mini-hydro schemes; the DNES expects that an allocation of about Rs. 1500 million (US Dollars 90 million) would be made available for mini-hydro development, 50% of which would be earmarked for irrigation based schemes.

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23/ The DNES provided grants to the APSEB for the development of pilot schemes on the Kakatiya D83 BC; additional funds have been earmarked for pilot schemes in Punjab state. The REC provided credits for the schemes in Tamil Nadu; and the PFC has provided a supplementary loan to develop a scheme in Karnataka.

5.4 It was assumed that up to 25% of the investment required to develop the schemes in each state will be mobilized in the form of equity contributions from the respective State Governments or the SEBs into the mini-hydro *"cost centers"*. The bulk of the financing (75%) for the mini-hydro "cost centers" would be obtained as loans from public agencies such as the Power Finance Corporation (PFC), the Rural Electrification Corporation (REC), 24/ and more probably the Indian Renewable Energy Development Agency (IREDA).

**IREDA Mini-Hydro Loan Facility**

In September, 1990, the Board of IREDA approved the following conditions for financial support to mini-hydro projects. Both public and private sector organizations, including those in the joint or cooperative sector were eligible for loans, provided the equity contribution of the principal sponsors would have to be at least 25% of the total investment required.

IREDA loans would not exceed 50% of the total cost of any mini-hydro scheme, up to a limit of Rs. 10 million. The IREDA "Guidelines for Financial Assistance" stipulates that: (i) the interest rate would be 12.5% p.a, with a rebate of 0.5% if repayment of principal and interest charges were made consistently punctual; (ii) loans would be repaid in 10 years, with a 3 year grace period; (iii) a loan commitment charge would be applied at 0.5% of loan amount up to a ceiling of Rs. 1.0 million; and (iv) a Bank Guarantee would be required to secure the loan.

Box 5.1

5.5 *Minimum Cashflow Requirements.* The current lending terms for these agencies are almost the same; therefore it is assumed that loans would be provided to the mini-hydro *"cost centers"* at 12.5% interest rate and an amortization period of 10 years. In Punjab State, where the financing for the schemes has already been secured under the ongoing Punjab Irrigation and Drainage Project, assuming that the funds are to be transferred by the State Government to a mini-hydro "cost center" in the PSEB as loans with terms similar to those offered by REC or PFC.

5.6 The minimum cashflow requirements of the mini-hydro *"cost centers"* were computed based on full recovery of costs incurred due to debt servicing plus the annual operation and maintenance of schemes (i.e., estimated to be 2% of capital cost per annum). The weighted average costs of generation for the "cost centers" in the southern states was estimated to vary from Rs.0.29/kWh in Kerala to 0.49/kWh in Andra Pradesh. Similarly in Punjab State, the weighted average cost of generation for the mini-hydro "cost center" was estimated to be Rs. 0.51/kWh.

5.7 *Revenues for the "Cost Centers".* Since the goal is to achieve economic cost recovery, it was assumed that revenues would accrue to the mini-hydro *"cost centers"* from the "sale" of energy to the grid; as such the financial value of the revenue generated by the mini-hydro "cost center" was established in terms of: (i) the tariff paid for bulk power imports from the National Thermal Power Corporation (NTPC); and (ii) the average tariff for power sales from the grid in each state.

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24/ The OECF of Japan has established a line of credit at the REC which may be used by the SEBs to finance some of the irrigation based mini-hydro schemes covered by this study. Schemes under consideration include Brindavan (Karnataka)and Lower Bhavani (Tamil Nadu).

**CASHFLOW BALANCE FOR SEB MINI-HYDRO "COST CENTERS"**

| STATE | TOTAL CAPACITY | ENERGY OUTPUT | WEIGHTED AV. COST | AVERAGE TARIFF | NET REVENUES FOR "COST CENTERS" |
|---|---|---|---|---|---|
| | (MW) | (GWh/yr.) | (Rs./kWh) | (Rs./kWh) | (Rs. millions p.a) |
| Andra Pradesh | 19.5 | 95.3 | 0.49 | 0.62 | 10.5-12.4 |
| Kerala | 26.6 | 120.0 | 0.29 | 0.53 | 28.8-37.4 |
| Karnataka | 37.7 | 170.0 | 0.44 | 0.73 | 27.3-49.4 |
| Tamil Nadu | 24.1 | 82.8 | 0.39 | 0.87 | 17.1-39.1 |
| Punjab | 22.2 | 133.0 | 0.51 | 0.67 | 12.0-21.4 |

Source:ESMAP estimates; SEBs and KPC.

Table 5.1

5.8 At present, the tariff for NTPC bulk power supply into the state grids in the southern region is Rs. 0.60/kWh. 25/ With the exception of Kerala, which is entirely dependent on hydropower, the average tariff for sales in the southern region is higher than the rate paid for NTPC supply. 26/ The average tariff for sales is Rs. 0.53/kWh for Kerala, and varies from Rs. 0.62-0.87/kWh in the other three states; for Punjab, the average tariff is Rs.0.67/kWh. As shown in *Table 5.1*, the net revenues in excess of minimum cashflow requirements would be positive for the mini-hydro "cost centers" in each state, indicating that the mini-hydro "cost centers" would be self-supporting.

### C. Return On Equity For Private Sector

5.10 The State Governments in Karnataka and Andhra Pradesh respectively are encouraging private companies to invest in mini-hydro schemes as an alternative source of captive generation. Recently, the Karnataka State Government approved leases for private development of several prospective mini-hydro sites including the canal drop scheme at Maddur, and the dam based scheme at Mudhol. The Andra Pradesh State Government also has offered leases to private investors for the development of all the mini-hydro prospects that are covered in this study (i.e.,the cluster of five schemes on the Guntur Branch Canal, the schemes on the Lock-In-Sula Regulator of the KC Canal, etc.).

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25/ The average cost of generation in PSEB thermal power stations is of the order of Rs.0.90/kWh; variable costs due to fuel and annual operation and maintenance is estimated to be Rs.0.60/kWh.

26/ The other states depend to a greater extent on higher cost thermal power stations. For example, the cost of power from TNEB's existing thermal power stations at Mettur and Ennore are estimated to be Rs.0.95/kWh and Rs.1.06/kWh respectively. The cost of generation at KPC's Raichur thermal power station is estimated to be at least Rs/0.75/kWh, and the cost of generation at APSEB's Vijayawada thermal station exceeds Rs.0.8/kWh.

5.11 The aim of the financial analysis was to determine the rate of return on equity for potential private investors, based on the conditions stipulated in lease agreements in Karnataka (Box 5.2), including restrictions on how financing should be mobilized; private companies would be required to contribute at least 25% in the form of equity, raise up to the maximum of 50% of the required capital investment for the schemes in the form of loans from IREDA (Box 5.1), and secure the balance as debt from private sources. It was assumed that private commercial loans would be secured for repayment over 6 years at an interest rate of 17%.

5.12 With the conditions of the lease agreements in Karnataka, and assuming that designs presented in this study are adopted, the cost of generation at the Maddur canal drop would be Rs.0.73/kWh. Similarly the cost of generation at Mudhol would be Rs.0.61/kWh. The installed capacity of the irrigation based mini-hydro schemes will not be available at all times during the year; this implies that the financial savings should be confined to the variable costs of industrial diesel auto-generation (Rs. 1.16/kWh).

### Terms of Lease Agreements in Karnataka

The State Government of Karnataka has offered private companies the option of obtaining long term leases to develop mini-hydro schemes on irrigation canals. The basic terms and conditions which are stipulated in recent lease agreements between the Karnataka State Government and a few private companies, and are pertinent to the analysis of the financial viability from the private company's perspective are as follows:

(a) a nominal fee of Rs.1000 per annum will be charged for the duration of the lease which allows for private ownership of the mini-hydro facilities to extend over a 40 year period;

(b) a royalty for water use will be charged at the rate of 10% of the prevailing electricity tariff for high tension industrial consumers. The royalty would be Rs.0.115/kWh at current tariff levels in the state;

(c) electricity duties will be levied from time to time, as is required by the state government;

(d) the cost of installing a transmission line to connect the mini-hydro scheme to the state grid will be borne by the private company. For each of the schemes reviewed by ESMAP, the estimates of total capital costs already include the grid-tie requirements;

(e) the operation and maintenance costs of the mini-hydro scheme would be borne by the private company. The O&M costs are estimated to be 1% of the total capital costs of each scheme; and

(f) a charge equivalent to 10% of energy wheeled through the state grid will be imposed by the KEB to cover the costs of power transmission from the captive mini-hydro scheme to the point of consumption by the private company.

Box 5.2

5.13 Taking into account the annual generation of each scheme, the deductions that would be allowed for depreciation (i.e., assuming 20 year straight line depreciation), wheeling charges to be levied by the Karnataka Electricity Board (KEB), but not the payments to be made to the State in lieu of electricity duties and the levies for maintenance of the irrigation reservoirs, the return on equity contributed by the private companies to develop each scheme would be 45% for the Maddur scheme, and 75% for the Mudhol scheme. *Prima facie* it would seem that development of the two schemes would be an attractive investment for private companies which need to secure a non-diesel source of captive power; private companies, especially those that plan to acquire diesel generators, would be in a position to pay royalty charges to gain access to the use of regulated water flows from irrigation reservoirs such as has already been proposed in Karnataka.

**RETURN ON EQUITY FOR PRIVATE INVESTORS**

| Scheme Name | Maddur | Mudhol |
|---|---|---|
| Installed Capacity (MW) | 2.0 | 1.0 |
| Annual Generation (GWh) | 8.93 | 5.20 |
| Wheeling Charge (10%) | 0.89 | 0.52 |
| Net Generation (GWh) | 8.04 | 4.68 |
| Capital Cost (Rs. million) | 24.26 | 11.40 |
| Construction Interest (Rs. million) | 3.03 | 1.43 |
| Total Financing (Rs. million) | 27.29 | 12.83 |
| Financing Plan (Rs. millions) | | |
| Equity (25%) | 6.82 | 3.21 |
| Public Financing (50%) | 13.65 | 6.41 |
| Private Financing (25%) | 6.82 | 3.21 |
| Total Investment | 27.29 | 12.83 |
| Cashflow Requirement (Rs. million/year) | | |
| Debt Servicing | 4.37 | 2.05 |
| Royalties (Rs.0.115/kWh) | 1.03 | 0.60 |
| O & M | 0.49 | 0.23 |
| Total Cashflow | 5.88 | 2.88 |
| Cost of Generation (Rs./kWh) | | |
| Mini-hydro Scheme | 0.73 | 0.61 |
| Standby Diesel Generator | 1.16 | 1.16 |
| Financial Savings (Rs. million) | | |
| Standby Diesel Generator | 3.44 | 2.55 |
| less Depreciation (5%/yr.) | (0.34) | (0.16) |
| Net Financial Savings (Rs. million) | | |
| Standby Diesel Generator | 3.10 | 2.39 |
| **Rate of Return on Equity** | **45%** | **75%** |

Source: ESMAP estimates

Table 5.2

# ANNEX A

## DERIVATION OF MINIMUM ANNUAL ENERGY PRODUCTIVITY

## ANNEX A: DERIVATION OF MINIMUM ANNUAL ENERGY PRODUCTIVITY

### Introduction

In order to improve the economic viability of irrigation based mini-hydro schemes, the primary objective for design is to maximize the number of kilowatt hours produced annually per unit of investment; the length of the irrigation season a critical factor in determining the economic viability of schemes since the aim is to achieve a high plant load factor. The concept of "minimum annual energy productivity" is a useful criteria for screening design proposals for prospectives schemes. The value of the minimum annual energy productivity is derived from the estimated economic value of energy, as presented below. The minimum value for economic viability remains a constant and does not change with plant factors.

### I. Derivation of Minimum Annual Energy Productivity

The key parameter is the economic value of the power to be supplied into the grid by the prospective irrigation based mini-hydro scheme; this value was determined to be Rs. 0.80/kWh, as indicated in Chapter 4 (paras. 4.3 through 4.7). Other parameters include: (i) the discount factor (12% p.a); (ii) the Standard Conversion Factor (0.80), which in accordance to standard World Bank practice in India is applied to convert financial costs into economic costs; (iii) the economic life of the mini-hydro schemes which is assumed to be 25 years; and iv the annual operating and maintenance (O&M) costs which is assumed to be 2% of the capital costs. From the above, the capital recovery factor was estimated to be 12.7% p.a. Also since is it assumed that construction would take 18 months, interest during construction is applied for one year at the 12% p.a. discount rate.

### II. Calculation of Maximum Tolerable Investment (Rs./kW)

The first step is to calculate the maximum tolerable investment per installed kilowatt which would enable power to be produced at or below the economic value for energy (i.e., Rs. 0.8/kWh). For illustrative purposes, it is assumed that the plant load factor would be 30% (i.e., the plant would produce 2628 kWh/kW installed capacity). The maximum tolerable investment per installed kW varies with plant load factor, as shown in Figure A1.

a. annual value of energy produced is (0.80 Rs./kWh x 2,628kWh/kW installed) or 2,102 Rs./kW installed.

b. the equivalent investment including construction interest charges is 2,102 Rs./kWh divided by the capital recovery factor plus annual O&M cost factor (i.e., 0.127+0.02).
The computed value is 14,254 Rs./kW

c. Hence, the equivalent investment less construction interest charges becomes 14,254 divided by 1.12 or 12,726 Rs./kW.

In economic terms, the maximum tolerable investment per kW installed = Rs. 12,726

In financial/commercial terms (i.e., after applying the Standard Conversion Factor of 0.8), the maximum tolerable investment per kW installed becomes (12,726 divided by 0.8) or 15,908 Rs./kW

### III. Calculation of Minimum Annual Energy Productivity per Rupee Invested

The minimum annual energy productivity per unit of investment is derived from the economic value of energy; it however is not dependent on the plant load factor and therefore is a more useful criteria for designing irrigation based mini-hydro schemes where different configurations with a range of plant load factors need to be screened. The value of the minimum annual energy productivity is derived by dividing the annual energy output of a given scheme by the maximum tolerable investment, as indicated below. The results for a range of values of the economic value of energy is shown in Figure A.2.

a. (2628 kWh/kW installed divided by 12,726 Rs./kWh) = 20.6 kWh p.a./100 Rs. invested in economic terms

b. 20.6 kWh p.a./100Rs. x SCF (0.8) becomes 16.5 kWh p.a./100 Rs. invested in financial terms

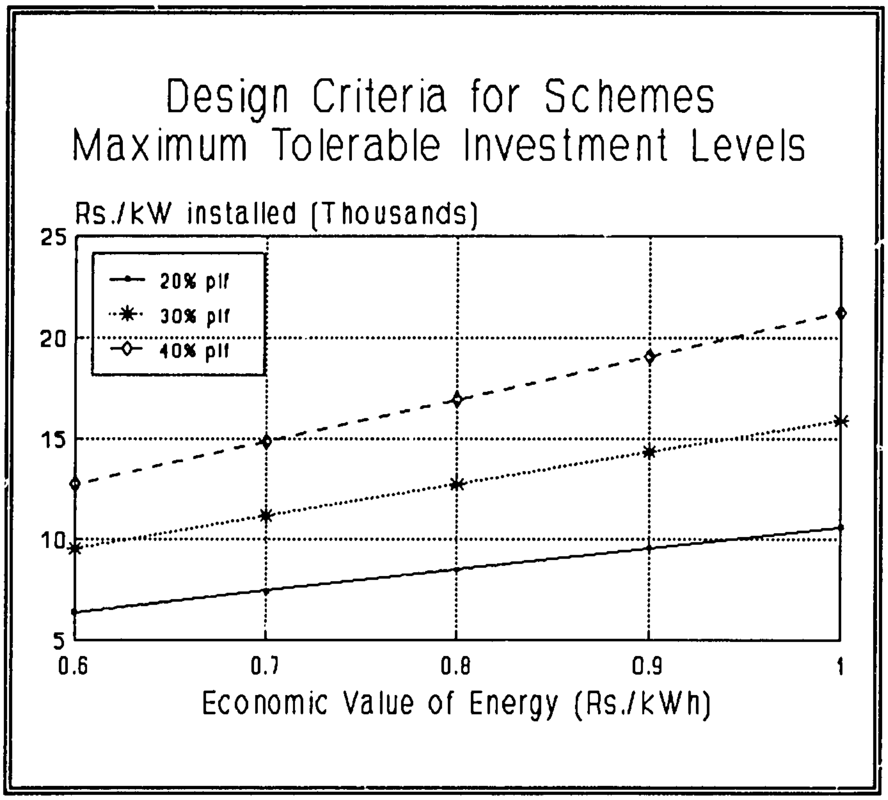



Figure A.1

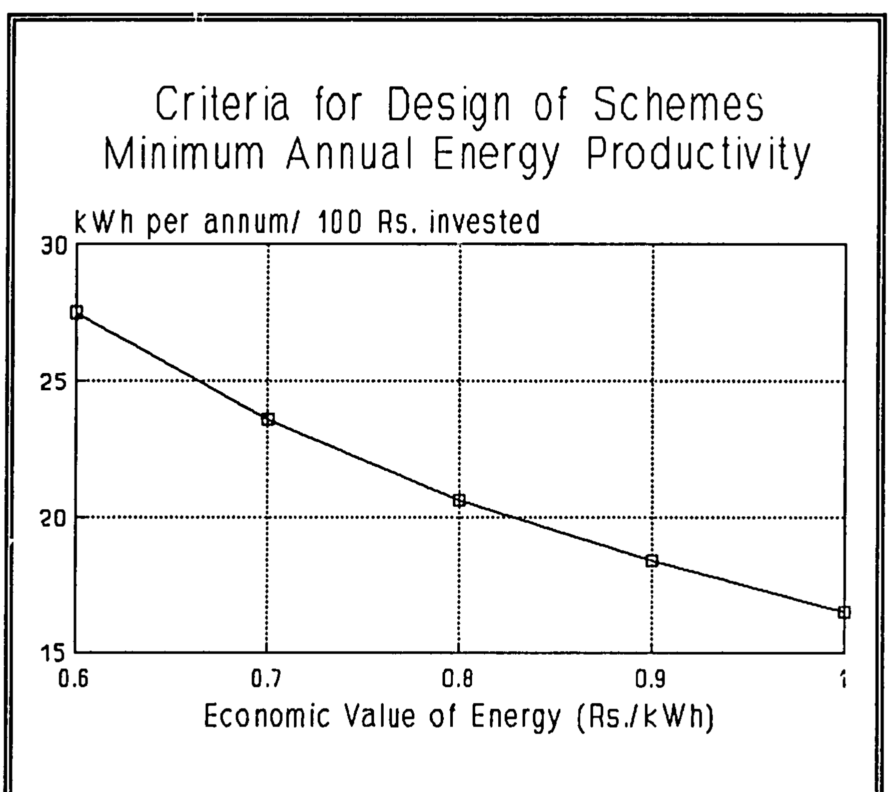



Figure A.2

LOWER BHAVANI MINI-HYDRO SCHEME

| | | | |
|---|---|---|---|
| Capacity (kW) | | 3*2500 | 2*3500 |
| Energy Output (GWh) | | 23.0 | 24.0 |
| Plant Load Factor (%) | | 0.4 | 0.4 |
| Cost Estimates | | | |
| Civil Structures | | 4.2 | 4.2 |
| Electro-Mech | | 20.5 | 18.3 |
| Electricals | | 15.6 | 18.4 |
| Grid-Tie | | | |
| Total | | 40.3 | 40.9 |
| Investment | (Rs./ kW) | 5373.3 | 5035.7 |
| Energy Productivity (kWh/Rs.) | | 8.6 | 8.8 |

Table A 1

KUTTIYADI MINI-HYDRO SCHEME

| | | |
|---|---|---|
| CAPACITY (kW) | 2*2000 | 2*1500 |
| ENERGY (GWh/Yr.) | 21.9 | 17.2 |
| COST ESTIMATES | | |
| CIVIL WORKS | 12.4 | 5.5 |
| ELECTRO-MECH | 8.9 | 8.9 |
| ELECTRICALS | 9.0 | 7.0 |
| GRID-TIE | 0.1 | 0.1 |
| | 30.4 | 21.5 |
| Investment (Rs./kW) | 7593 | 7187 |
| Energy Prod (kWH/100 Rs) | 72.1 | 79.8 |

Table A2

PEECHI MINI-HYDRO SCHEME

| | | |
|---|---|---|
| Capacity (kW) | 1500 | 1000 |
| Energy Output (GWh) | 10.0 | 6.9 |
| Plant Load Factor (%) | 0.7 | 0.7 |
| Cost Estimates | | |
| Civil Structures | 2.0 | 2.0 |
| Electro-Mech | 4.4 | 3.3 |
| Electricals | 3.3 | 3.0 |
| Grid-Tie | | |
| Total | 9.7 | 8.3 |
| Investment (Rs./kW) | 6480 | 8138 |
| Energy Productivity (kWh/100 Rs.) | 103.1 | 83.1 |

Table A 3

MANIYAR MINI-HYDRO SCHEME

| | | |
|---|---|---|
| Capacity (kW) | 6*2500 | 3*5000 |
| Energy Output (GWh) | 56.8 | 50.5 |
| Plant Load Factor (%) | 0.4 | 0.4 |
| Cost Estimates | | |
| Civil Structures | 13.0 | 13.0 |
| Electro-Mech | 41.0 | 31.5 |
| Electricals | 31.0 | 48.3 |
| Total | 85.0 | 92.8 |
| Investment (Rs./kW) | 5665 | 6187 |
| Energy Productivity (kWh/Rs.) | 10.0 | 8.2 |

Table A4

# ANNEX B

# DETERMINATION OF DESIGN HEAD

# FOR

# DAM BASED SCHEMES

# ANNEX B: DETERMINING THE DESIGN HEAD FOR DAM BASED SCHEMES

**The Lower Bhavani Scheme, Tamil Nadu**

Lower Bhavani Irrigation dam is located in Satyamangalam Taluq of Periyor District in Tamil Nadu, and is about 60 km by road from the city of Coimbatore. The dam discharges through five sluices, each of which has a dimension of 1.83m x 3.05m, and can handle an equivalent of 30 cumecs. The TNEB proposal would utilize discharges through two sluices, hence the remaining three sluices would be used as by-passes in the event one or two units are shut down.

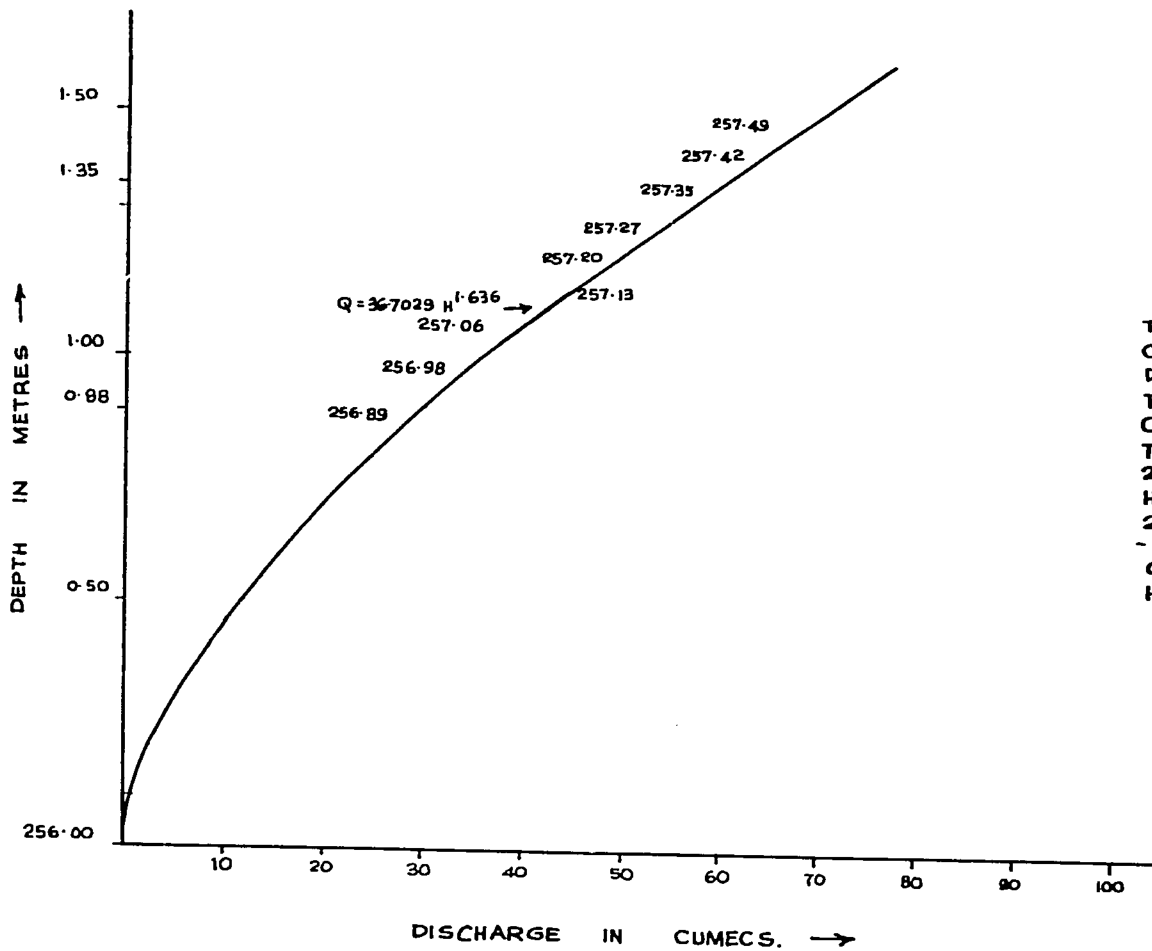
**Head Duration Curve**

The TNEB provided ESMAP with 15 year series reservoir data on water draw down levels and tail water levels respectively. The data was used by ESMAP to prepare a series of curves to explore the relationship between head, flood rise level (FRL) in the reservoir and tailwater levels, etc. as shown in the graphs. From the head duration curve, it is apparent that the variation in head for an average year would be 15.92 m for a tailwater level (TWL) of 259.60 and 16.92 m for a TWL of 258.60m. For 1974, which was selected as a critical year for design purposes, a head of 16m and above was available for only about 10% of time (at TWL of 256.52). The equivalent availability for other heads were as follows: (i) 15m - 30%; (ii) 13m - 54%; (iii) 11m - 70%; and (iv) 9m - 82%. A gross head of 15.5m was available for 20% of the time.

**Tailwater Rating Curve**

The other curves shown below are based on the following relationships. The variation in gross head is plotted with changes in: (i) discharge level (at a reservoir draw down level of 268.3); (ii) discharge level (at a reservoir FRL of 280.25); and (iii) the installed capacity, is plotted in the other two curves respectively. These are represented as H = f(Q) at reservoir level 268.30; (ii) H = f(a) at FRL 280.25, and (iii) H = f(N), where N is 3500 kW, 7000 kW and 10,500 kW, based on H = N/8.5Q. The intersection points "A" indicate for a discharge of 36 cumecs (draw down level of 268.30 meters, N = 3500kW), the available head would be 11.2 meters. Similarly the intersection point "C" indicates that the net head would be only 10.5m for discharges of 80 cumecs for an installed capacity of N = 7000 kW.

For an installed capacity of 7000 kW, the reservoir level would fall to 268.8 meters. The sluices would be required to handle discharges of 78.5 cumecs which would be about 10 cumecs more than the maximum available discharge (67 cumecs) that was available during the entire 15 year period covered by the data. If the minimum reservoir level increased from 268.86 to 274.4, a discharge of 48 cumecs would allow for a guaranteed output of 7000 kW for a head of 17.2 meters. By restricting the discharges to 60 cumecs, the draw down level would fall to about 273 meters, and an 7000 kW output could be maintained at a design head of 15.5 meters.



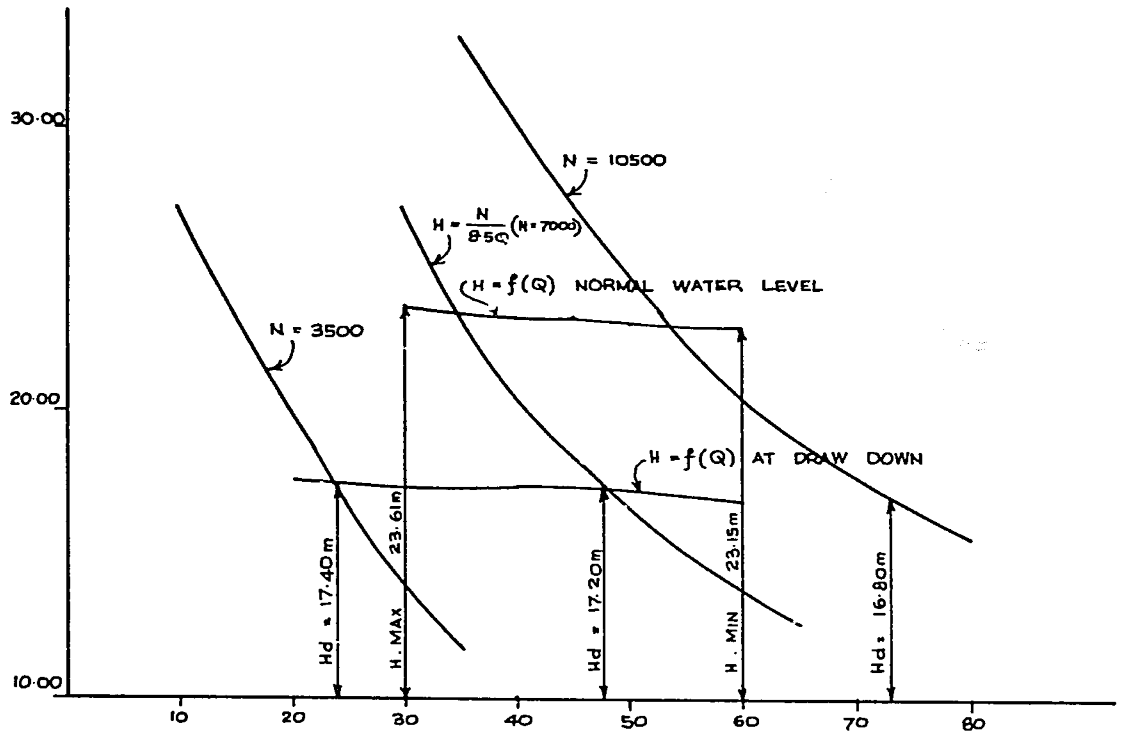

TAIL RATING CURVE IS BASED ON CANAL FLOWS WITHOUT POWER HOUSE D/S OF SLUICE. THE MINIMUM TAIL WATER TAKING INTO SUBMERGENCE OF DRAFT TUBE OUT LET IS 259·60m THIS LEVEL HAS BEEN LOWERED TO 258·60 WITH INCLINED DRAFT TUBE HENCE FOR NET HEAD CALCULATIONS 258·60 – 256·89 = 1·71 m IS CONSI-DERED LOST DUE TO SUBMERGENCE CONDITION AGAINST 2·71 m FOR HORIZONTAL DRAFT TUBE

LOWER BHAWANI

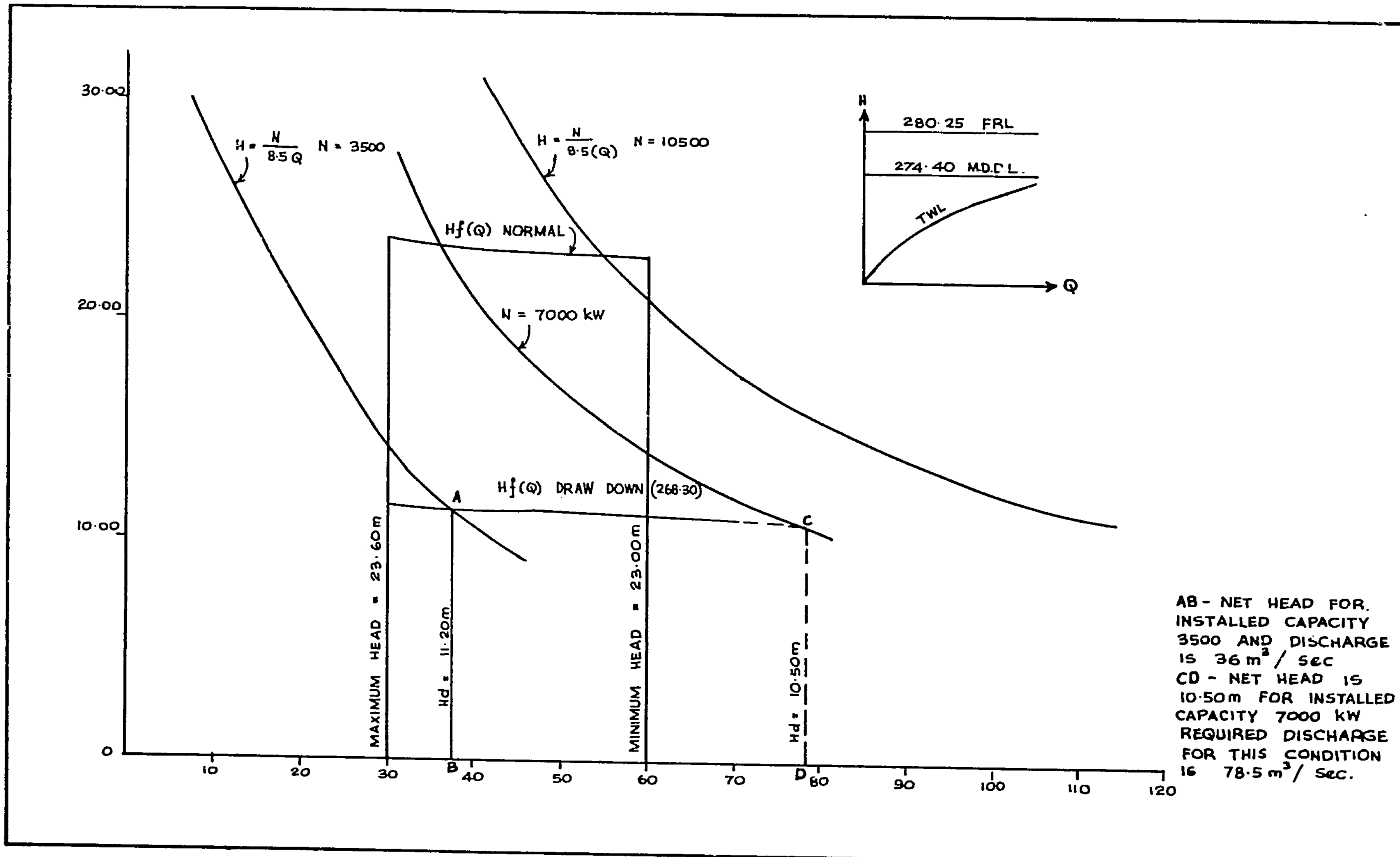
MINI HYDRO POWER PROJECT

TAIL WATER RATING CURVE

SHEET 1 OF 2




SHEET 1 OF 2 INDICATES NET HEAD FOR DRAW DOWN LEVEL OF 268·30. THIS SHEET INDICATES Q Vs H CONDITIONS FOR DRAW DOWN LEVEL OF 274·40


30.00
20.00
10.00
0
10
20
30
40
50
60
70
80
90
100
110
120
H = N / 8.5 Q  N = 3500
H = N / 8.5(Q)  N = 10500
Hf(Q) NORMAL
N = 7000 kW
Hf(Q) DRAW DOWN (268.30)
A
B
C
D
MAXIMUM HEAD = 23.60 m
Hd = 11.20 m
MINIMUM HEAD = 23.00 m
Hd = 10.50 m
H
Q
280.25 FRL
274.40 M.D.D.L.
TWL
AB - NET HEAD FOR INSTALLED CAPACITY 3500 AND DISCHARGE IS 36 m³/ Sec
CD - NET HEAD IS 10.50 m FOR INSTALLED CAPACITY 7000 kW REQUIRED DISCHARGE FOR THIS CONDITION IS 78.5 m³/ Sec.

## The Brindavan Scheme, Karnataka

The Brindavan Dam is located on the KRS reservoir, which is part of the Cauvery River basin. The proposed mini-hydro schemes would utilize discharges from the dam into the Visveswaraiah Main Canal.

## Head Duration Curve and Tailwater Curve

The proposed Brindavan minihydro project near Mysore envisages utilization of flows in three vents which feed the Viswesawaraiah Canal. Based on the analysis the relationship between head and discharge levels (i.e., the TWL rating curve), and the head and draw down levels for a range of installed capacities, the available head would exceed 13 meters for 50% of time. Hence 13 meters is used by ESMAP as the design head.

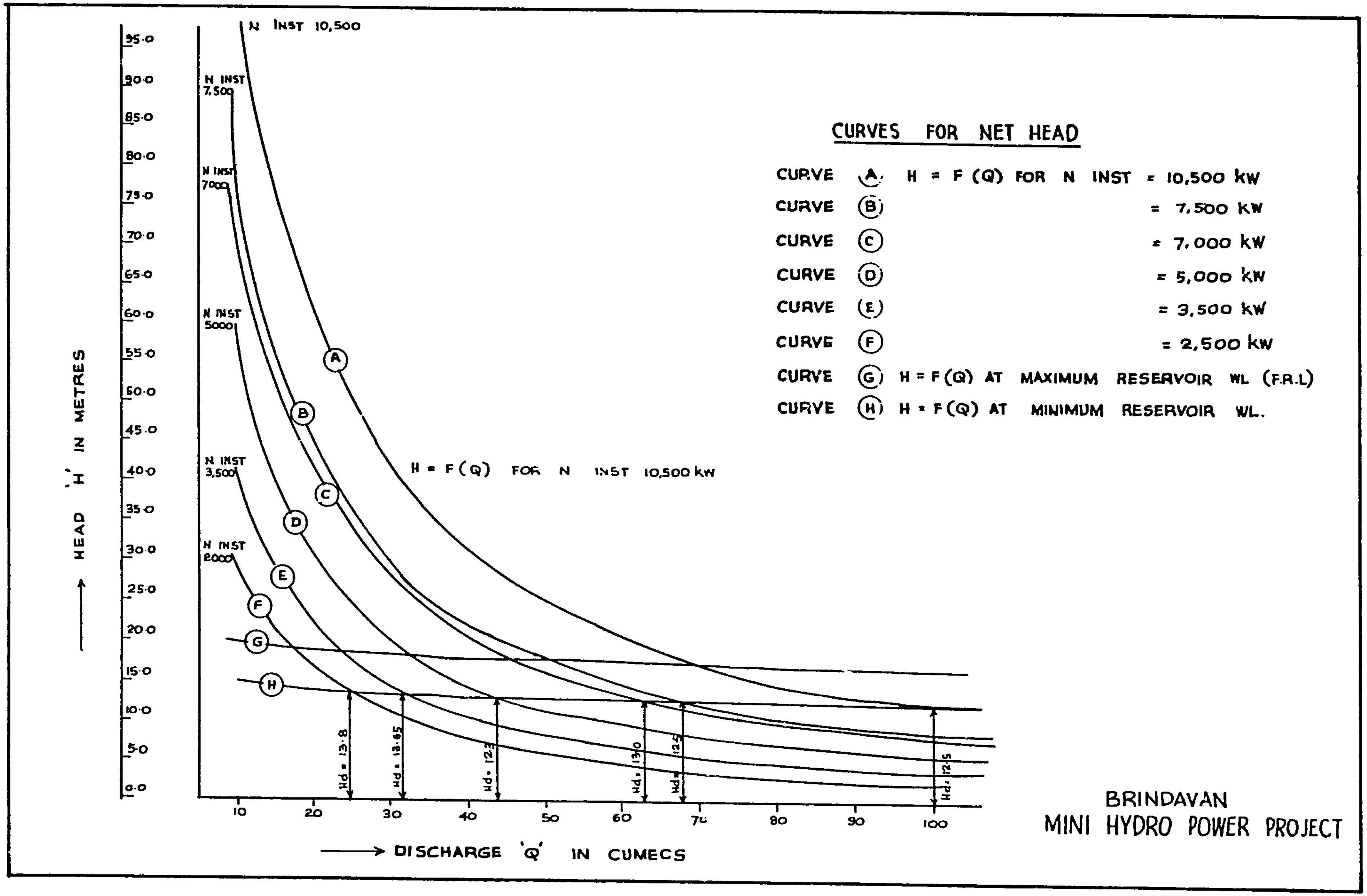
Table B.1: Brindavan Dam Mini-Hydro Scheme:
Design Calculations for Net Head

| Discharge-Q (cumecs) | TWL (meters) | Head (meters) relative to FRL | Head (meters) relative to MDDL |
|---|---|---|---|
| 10 | 733.45 | 18.80 | 14.14 |
| 20 | 733.70 | 18.55 | 13.89 |
| 30 | 733.90 | 18.35 | 13.89 |
| 40 | 734.08 | 18.17 | 13.51 |
| 50 | 734.23 | 18.02 | 13.36 |
| 60 | 734.40 | 17.85 | 13.19 |
| 70 | 734.57 | 17.68 | 13.02 |
| 80 | 734.68 | 1757 | 12.91 |
| 90 | 734.80 | 17.45 | 12.79 |
| 100 | 734.92 | 17.33 | 12.67 |

H= F(Ninst)
= Ninst/8.5 Q

| Discharge-Q (cumecs) | Head (meters) for Ninst= 5000 kW | Head (meters) for Ninst= 3500 kW | Head (meters) for Ninst= 2500 kW |
|---|---|---|---|
| 10 | 58.80 | 41.18 | 29.41 |
| 20 | 29.41 | 20.59 | 14.71 |
| 30 | 19.60 | 13.73 | 09.80 |
| 40 | 14.71 | 10.29 | 07.35 |
| 50 | 11.77 | 08.24 | 05.88 |
| 60 | 09.80 | 06.86 | 04.90 |
| 70 | 08.40 | 05.88 | 04.20 |
| 80 | 07.35 | 05.15 | 03.68 |
| 90 | 06.54 | 04.50 | 03.27 |
| 100 | 05.88 | 04.10 | 02.94 |

| Discharge-Q (cumecs) | Head (meters) for Ninst= 7000 kW | Head (meters) for Ninst= 7500 kW | Head (meters) for Ninst= 10500 kW |
|---|---|---|---|
| 10 | 82.35 | 88.23 | 123.53 |
| 20 | 41.18 | 44.12 | 61.77 |
| 30 | 27.45 | 29.41 | 41.18 |
| 40 | 20.59 | 22.06 | 30.88 |
| 50 | 16.47 | 17.65 | 24.71 |
| 60 | 13.73 | 14.71 | 20.59 |
| 70 | 11.76 | 12.61 | 17.65 |
| 80 | 10.29 | 11.03 | 15.47 |
| 90 | 09.15 | 09.80 | 13.73 |
| 100 | 08.24 | 08.82 | 12.35 |


CURVES FOR NET HEAD
CURVE (A) H = F (Q) FOR N INST = 10,500 kW
CURVE (B) = 7,500 KW
CURVE (C) = 7,000 kW
CURVE (D) = 5,000 kW
CURVE (E) = 3,500 kW
CURVE (F) = 2,500 kW
CURVE (G) H = F (Q) AT MAXIMUM RESERVOIR WL (F.R.L)
CURVE (H) H = F (Q) AT MINIMUM RESERVOIR WL.
N INST 10,500
N INST 7,500
N INST 7000
N INST 5000
N INST 3,500
N INST 2000
H = F (Q) FOR N INST 10,500 kW
HEAD 'H' IN METRES
DISCHARGE 'Q' IN CUMECS
Hd = 13.8
Hd = 13.65
Hd = 12.3
Hd = 13.0
Hd = 12.5
Hd = 12.5
BRINDAVAN
MINI HYDRO POWER PROJECT

# ANNEX C

## BY-PASS ARRANGEMENTS

## FOR

## IRRIGATION BASED MINI-HYDRO SCHEMES

## ANNEX C: BY-PASS ARRANGEMENTS FOR IRRIGATION BASED MINI-HYDRO SCHEMES

Irrigation flows should not at all be disrupted by the operation of the mini-hydro schemes. This is a critical design condition which requires the installation of appropriate by-pass arrangements for most schemes. The main types of by-pass arrangement that are considered by ESMAP to be compatible with the designs presented in this report are reviewed below.

### By-Pass Arrangements for Dam-Based Schemes

The main objective is to maintain irrigation discharges through dam sluices when the mini-hydro scheme has to be shut down at short notice because of operational problems such as a short circuit or system failure. In several of the schemes covered in this study, there would not be a major problem because there would be adequate capacity in the remaining sluices to handle the required discharge levels. For a few schemes such as the Brindavan Dam in Karnataka, the plan is to install penstocks turbines in each of the three sluices; by-pass arrangements are therefore necessary to ensure that irrigation operations would continue even when the units have to be shut down.

The flow duration curve for Brindavan indicates that the irrigation discharges vary from almost zero to as high as 300 cumecs; however the maximum discharge to be handled by the mini-hydro scheme would be 100 cumecs. Hence during the 60 days (i.e., 18% duration level) that irrigation discharges would exceed 100 cumecs, all the surplus flows (about 50-60 cumecs in each sluice) has to be released through a by-pass arrangement.

The proposed configuration of the scheme is 3 units of 3500 kW each, would require the discharge of 30 cumecs through each sluice; each of the sluices has an cross-sectional areas of 7 square meters and hence the discharges would occur at a velocity of about 4 m2/sec. However to accommodate the maximum discharge of 100 cumecs per sluice, the velocity would be about 13 m2/sec., which can only be handled by lining the sluices with steel. Accordingly the proposed by-pass arrangement would be in the form of a steel conduit.

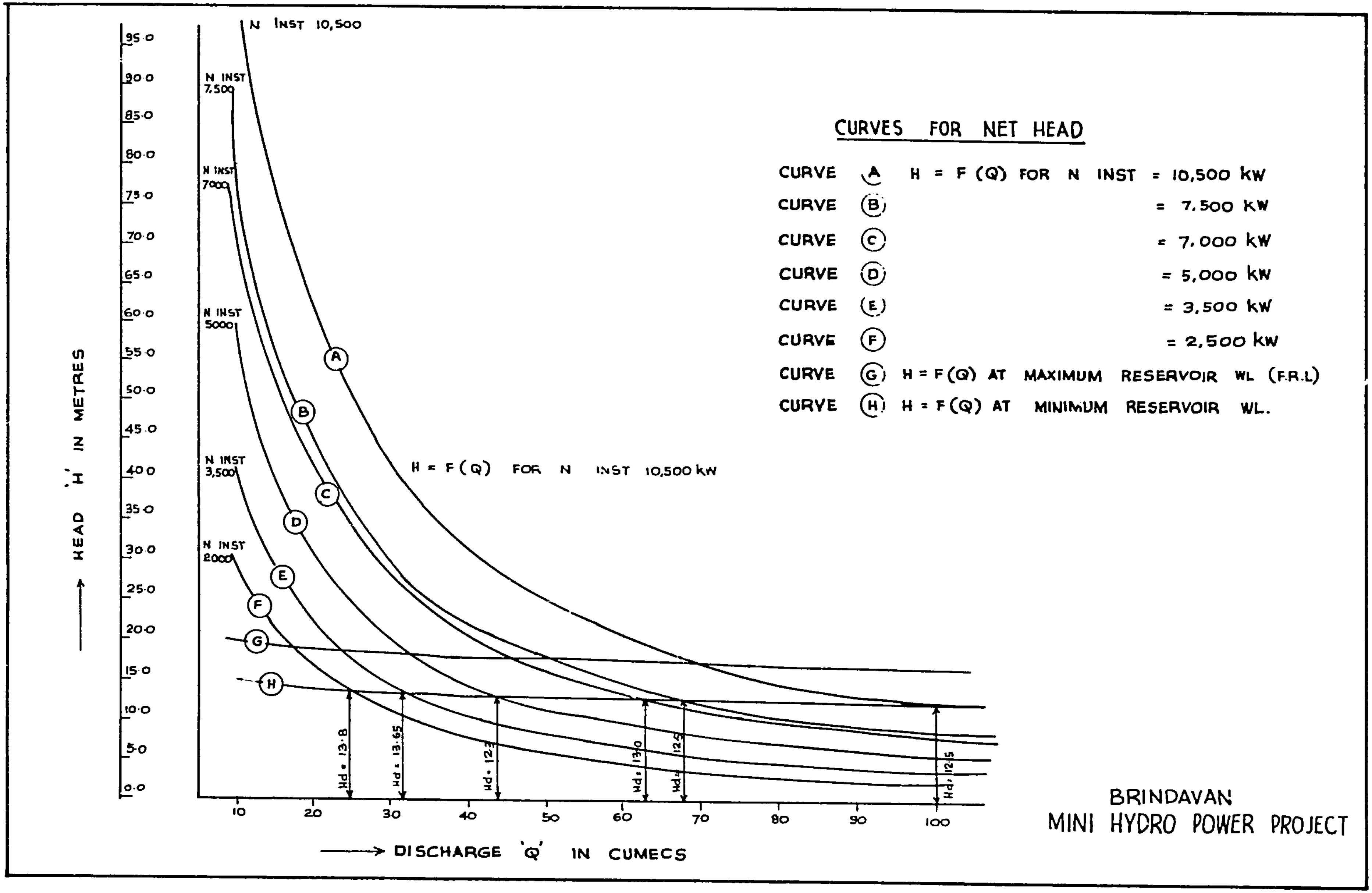
The steel conduit would be a pipe of about 2.5 to 3.0 meters in diameter which would be connected to the penstock at a point slightly upstream of the intake to the power house. A pressure regulator may not be necessary because the existing canal structure is able to fully absorb the hydraulic jump immediately downstream of the sluices. The proposed arrangement is shown in the drawings below.

### By-Pass Arrangement for Canal Drop Schemes

For canal drop schemes, the alternatives would involve: (i) installing the by-pass immediately upstream of the powerhouse; or (b) installing automatically regulated crest gates at the drop structure. For illustrative purposes, the options for the Guntur Branch Canal are reviewed.

The canal which is designed to handle about 80 cumecs, has a bed width of the Guntur Branch Canal is 22 meters; the side walls have a slope of 1:1, the depth of the flows is about 3 meters, and the free board is 1 meter. The drop structure at the proposed scheme is 25 meters wide. Since the location of the powerhouse (i.e., on the by-pass channel) is relatively far from the drop structure, there may be some difficulties in synchronizing the operation of crest gates and the turbines. Moreover, mechanical means have to be used to operate the gates which would be large (i.e., 25 meters wide).

The recommended arrangement would be to install a by-pass at the powerhouse, using one of the three configurations which are illustrated below.


CURVES FOR NET HEAD
CURVE (A) H = F (Q) FOR N INST = 10,500 kW
CURVE (B) = 7,500 kW
CURVE (C) = 7,000 kW
CURVE (D) = 5,000 kW
CURVE (E) = 3,500 kW
CURVE (F) = 2,500 kW
CURVE (G) H = F(Q) AT MAXIMUM RESERVOIR WL (F.R.L)
CURVE (H) H = F(Q) AT MINIMUM RESERVOIR WL.
N INST 10,500
N INST 7,500
N INST 7000
N INST 5000
N INST 3,500
N INST 2000
H = F (Q) FOR N INST 10,500 kW
Hd = 13·8
Hd = 13·65
Hd = 12·3
Hd = 13·0
Hd = 12·5
Hd = 12·5
HEAD 'H' IN METRES
DISCHARGE 'Q' IN CUMECS
0·0
5·0
10·0
15·0
20·0
25·0
30·0
35·0
40·0
45·0
50·0
55·0
60·0
65·0
70·0
75·0
80·0
85·0
90·0
95·0
10
20
30
40
50
60
70
80
90
100
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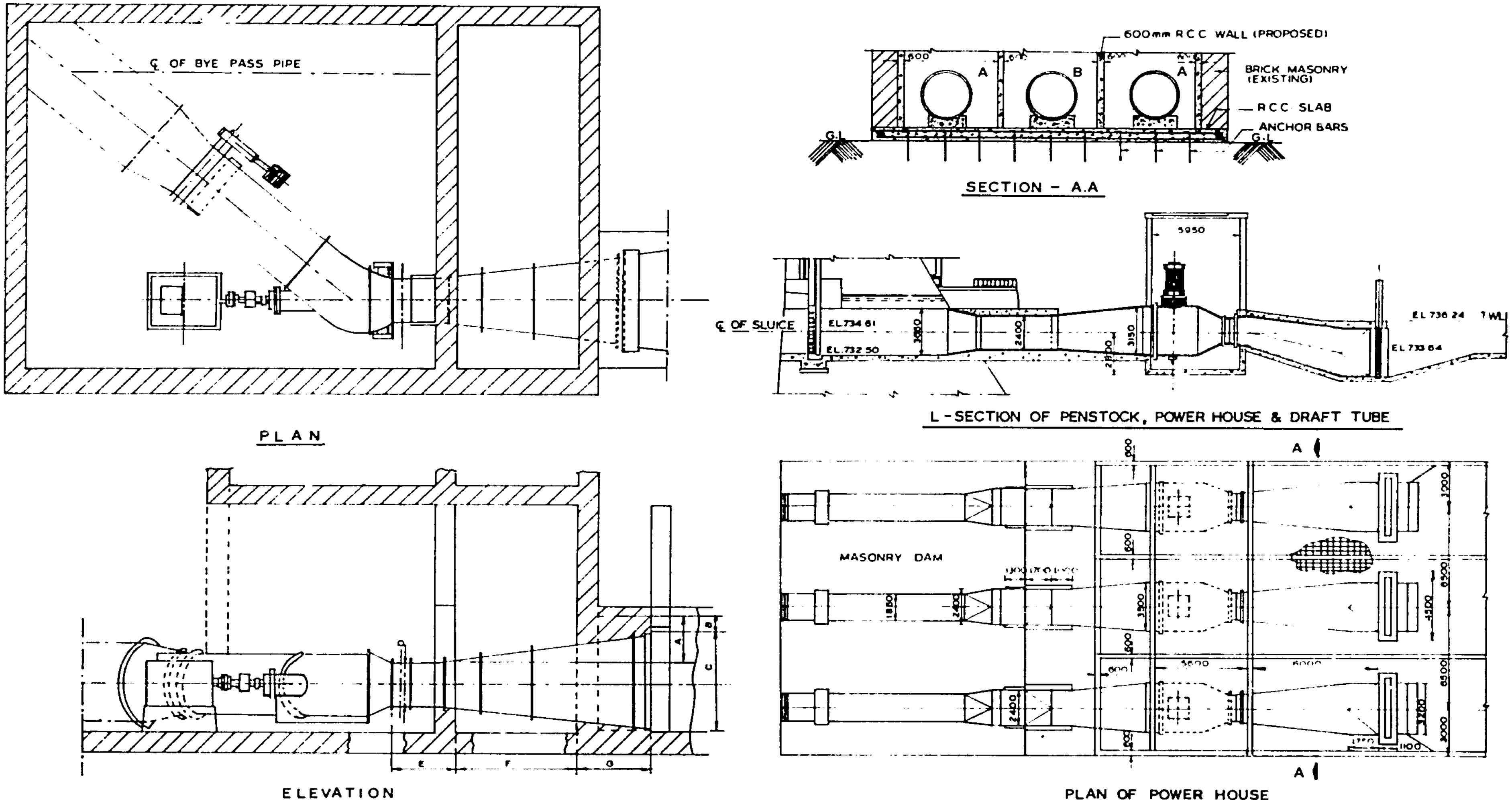


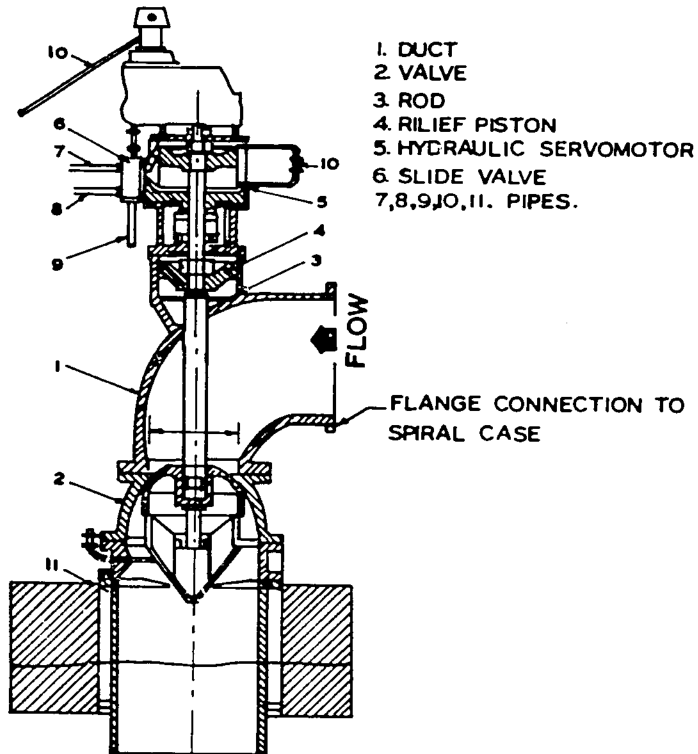

UPSTREAM ELBOW WITH CROSS WALLS, LONGITUDINAL WALLS AND BYE PASS PIPE CENTRE LINE. THE CELLULAR STRUCTURE WILL SERVE AS COFFER DAM FOR EACH UNIT

NOTES:-

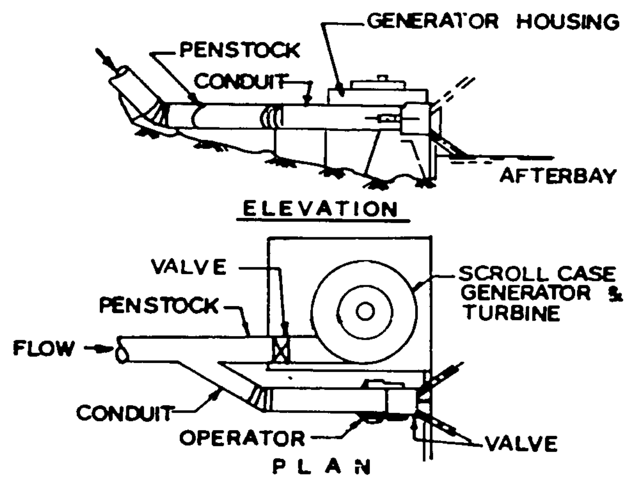
'A' AND 'B' IN SECTION A.A INDICATES PHASE-I AND PHASE CONSTRUCTION. DRILLING FOR FOUNDATION ANCHORS IS WITH JACK HAMMER ROCK EXCAVATION IN TAIL RACE IS WITH DRILLING AND WEDGING

MINI HYDRO POWER PROJEC
ESMAP STUDY

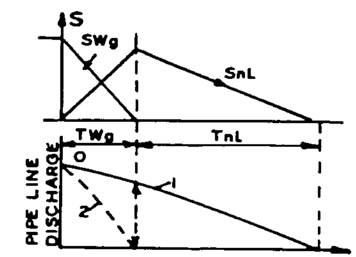
DAM BASED SCHEMES WITH ALTERNATIVE POWER HOUSE LAYOUT




TURBINE PRESSURE REGULATOR

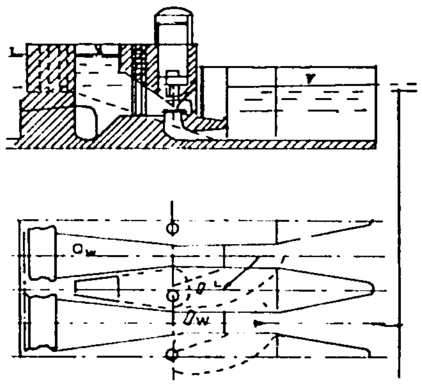



ARRANGEMENT OF A SYNCHRONOUS BYPASS VALVE



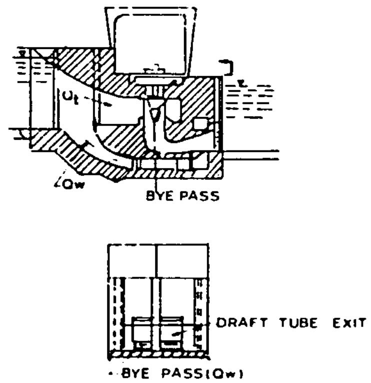

OPERATION OF PRESSURE REGULATOR

**MINI HYDRO POWER PROJECT**
ESMAP STUDY
**BYE PASS WITH HOLLOW BUNGER VALVE AND PRESSURE REGULATOR**




PIT TURBINE WITH BYE PASS

I

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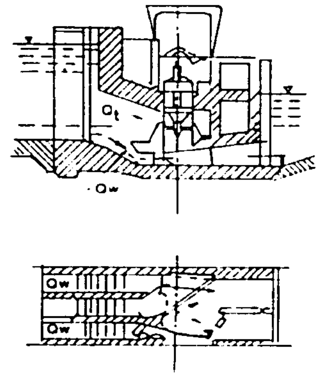
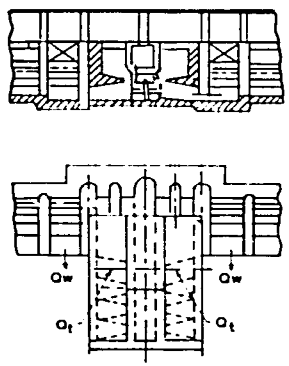


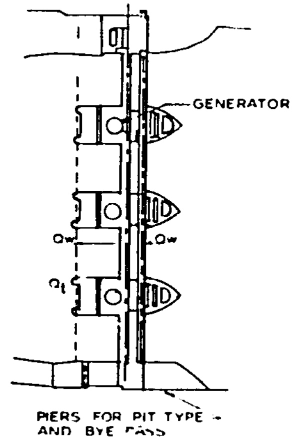

III

## DIFFERENT DESIGNS OF COMBINED HPPS

(BYE PASS AND TURBINE FLOW)




IV




V

**LEGEND:-**

$Q_t$ - FLOW THROUGH TURBINE.

$Q_w$ - BYE PASS SPILL.

**NOTES :-**

I PIT TYPE (DRAFT TUBE EXIT TO BYE PASS)

II VERTICAL SHAFT WITH ELBOW DRAFT TUBE, BYE PASS BELOW DRAFT TUBE

III VERTICAL SHAFT BYEPASS JOINING DRAFT TUBE

IV $Q_t$ EXITING INTO BYE PASS SPILLWAY CHANNEL

V PIT TYPE PIER OUTLINE

I TO V APPLICABLE FOR HEADS UPTO 10 METRES

**BYE PASS FOR DAM & CANAL BASED POWER STATION**

By-Pass Arrangement for Closed Conduits

The options for such schemes (e.g., Kuttiyadi) would be similar to those for the dam based schemes that use penstocks. To maintain the pressure in the conduits, the appropriate arrangement would be to install a pressure regulator valve, as illustrated below.

# ANNEX D

## UNIT COSTS OF EQUIPMENT

## (1990 PRICES)

## ANNEX D: UNIT COSTS OF EQUIPMENT FOR MINI-HYDRO SCHEMES

(1990 Prices)

### Main Components for Costing Schemes.

1. The total capital costs for each of the prospective mini-hydro schemes are derived according to the following components:

(i) Hydro-mechanical Equipment, comprising of the turbines (including auxiliaries) and inlet valves;

(ii) Electrical Equipment, comprising the induction generators (including auxiliaries), transformers, and other electrical equipment such as breakers, switches, fuses, etc.;

(iii) Civil Structures, comprising the intake structure, water conveyance structures (e.g., penstocks, open channels, concrete conduits, draft tubes, etc.), powerhouse structure, and water level control structures (e.g. gates, stop logs).

### Cost of Hydro-Mechanical Equipment

Table 1: Unit Costs - Inlet Valve, Turbine and Auxiliaries
(Rs. millions)

| Runner Diameter (mm) | 2800 | 2500 | 2000 | 1800 | 1600 | 1400 | 1250 | 1000 |
|---|---|---|---|---|---|---|---|---|
| Inlet Valves | 0.9 | 0.7 | 0.5 | 0.4 | 0.3 | 0.25 | 0.2 | 0.18 |
| Turbine & Auxiliaries | 9.2 | 8.0 | 6.0 | 5.5 | 5.0 | 4.0 | 3.0 | 2.5 |

Note: Inlet valve diameters are 200-300 mm. larger than runner diameters.

### Cost of Electrical Equipment

Table 2: Electrical Costs - Induction Generators and Auxiliaries
(Rs million)

| Capacity (KW) | 350 | 650 | 1000 | 1250 | 1500 | 2000 | 2500 | 3500 |
|---|---|---|---|---|---|---|---|---|
| Cost (Rs. Millions) | 0.7 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 4.0 | 7.5 |

Table 3: Electrical Costs - Transformers
(Rs. million)

| Voltage (KV) | 0.415/11 | | | 3.3/22 | 3.3/33 | | | 11/110 | |
|---|---|---|---|---|---|---|---|---|---|
| KVA | 500 | 1200 | 1750 | 5000 | 1625 | 3125 | 4700 | 13250 | 18750 |
| Costs | 0.2 | 0.3 | 0.4 | 0.9 | 0.5 | 0.6 | 0.8 | 2.0 | 2.5 |

| Voltage (KV) | 3.3/11 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| KVA | 1250 | 1625 | 2500 | 3125 | 3750 | 5000 | 5625 | 6250 | 9000 |
| Costs | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.3 |

**Other Electrical Items:**

Table 4: Electrical Cost Breakers, A.B. Switches, H.G. Fuses, Lightning Arrestors and Pole Structures (Rs million)

| Voltage (KV) | 11 | 22 | 33 | 110 |
|---|---|---|---|---|
| Breakers | 0.15 | 0.2 | 0.22 | 0.45 |
| A.B.Switches | 0.005 | 0.006 | 0.009 | 0.02 |
| H.G.Fuses | 0.001 | 0.002 | 0.005 | - |
| Lightning Arrestors | 0.005 | 0.006 | 0.008 | 0.054 |
| Pole Structures a/ 2p | 0.02 | 0.02 | 0.03 | |
| 4p | 0.04 | 0.04 | 0.06 | |
| 6p | 0.06 | 0.06 | 0.08 | |

a/ see attached schematic on pole structures.

**Installation Costs**

In the absence of data on the actual costs of installing mini-hydro equipment in India (i.e., turbine and auxiliaries, generators with auxiliaries, and switchyard equipment), the installation costs have been estimated taking into account the following points:

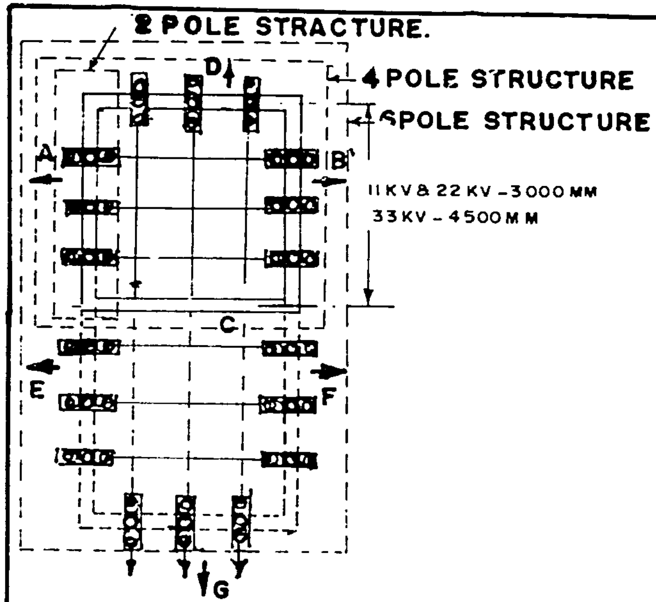
1) Total number of similar runners

2) Total number of similar generators.

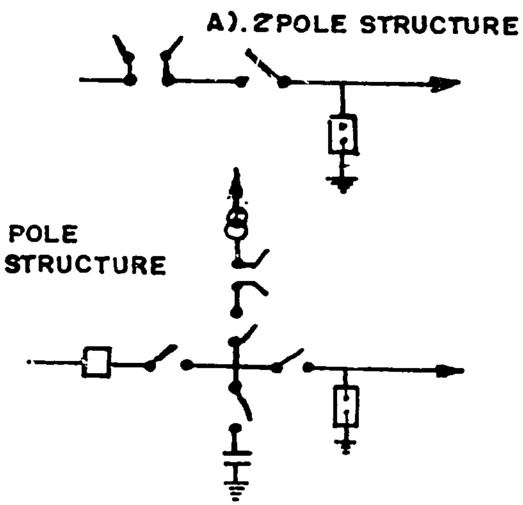
3) Runner installation takes place during early and middle stages of project construction when facilities are restricted.

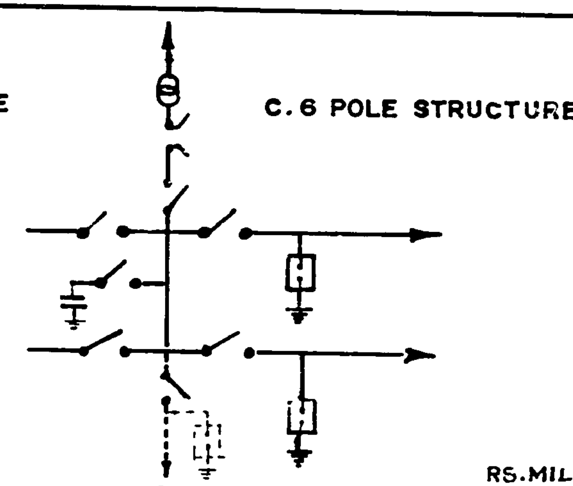
4) Alignment levels of equipment have to be carefully fixed and delay in civil works may upset erection schedule.

| Runner diameter (mm) | Generator Capacity (kW) | No. of Units | Erection (% of electro-mech) | Costs (%of electricals) |
|---|---|---|---|---|
| 2800 | 1000 | 10 | 4 | 5 |
| | | | | |
| 2500 | 3500 | 5 | 5 | 5 |
| | 1000 | 2 | 5 | 6 |
| | 650 | 13 | 5 | 5 |
| | | | | |
| 2000 | 2500 | 6 | 5 | 7 |
| | 1500 | 4 | 5 | 7 |
| | 1250 | 8 | 5 | 5 |
| | 1000 | 2 | 5 | 7 |
| | 350 | 5 | 5 | 7 |
| | | | | |
| 1400 | 2000 | 2 | 4 | [illegible] |
| | 1500 | 5 | 4 | 6 |
| | 1000 | 3 | 4 | 4 |
| | 650 | 13 | 4 | 3 |
| | 350 | 6 | 4 | 3 |
| | | | | |
| 1250 | 1500 | 1 | 4 | 7 |
| | 1000 | 3 | 4 | 7 |
| | 650 | 7 | 4 | 6 |
| | 350 | 18 | 4 | 4 |
| | | | | |
| 1000 | 1250 | 2 | 4 | 4 |
| | 350 | 4 | 4 | 4 |



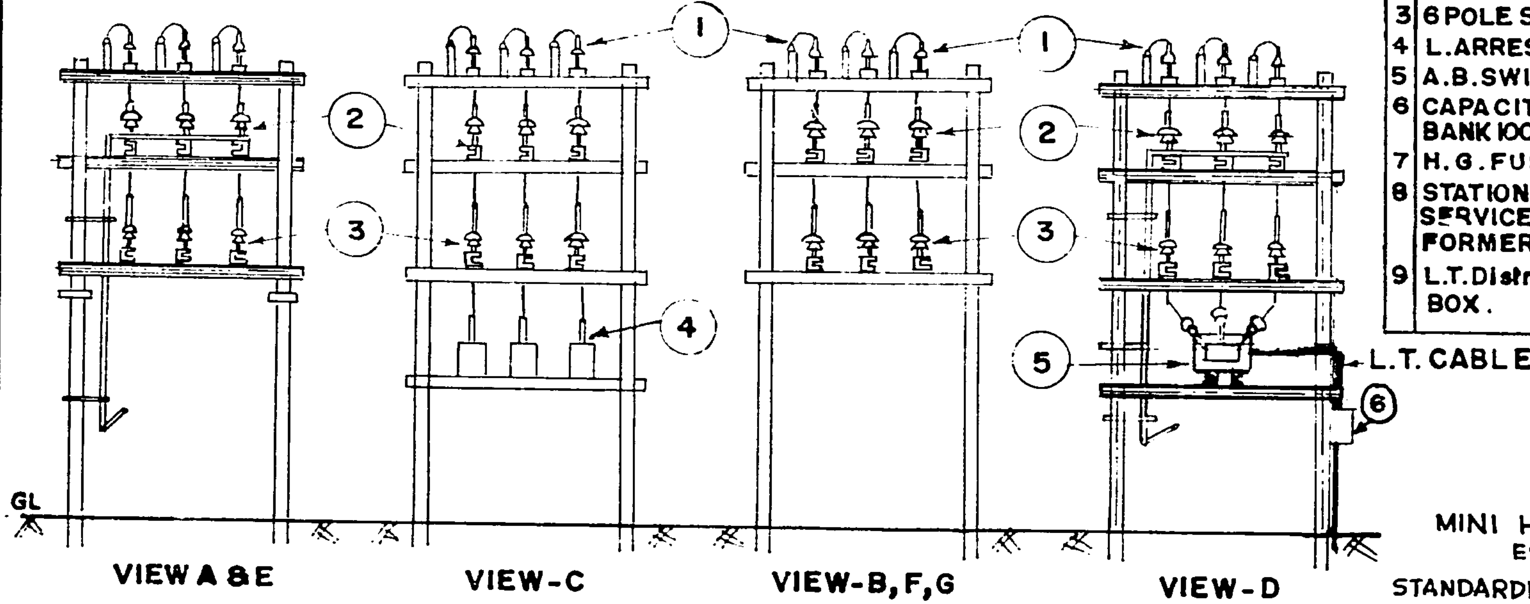

## SINGLE LINE DIAGRAM




RS. MILLION

| Sl | DESCRIPTION | 11KV | 22KV | 33KV |
|---|---|---|---|---|
| 1 | 2 POLE STRUCT | .015 | .015 | .02 |
| 2 | 4 POLE STRUCT | .04 | .04 | .05 |
| 3 | 6 POLE STRUCT | .055 | .055 | .075 |
| 4 | L. ARRESTOR | .0015 | .0015 | .005 |
| 5 | A.B. SWITCH | .005 | .008 | .01 |
| 6 | CAPACITOR BANK 100 KVAR | .015 | .02 | .025 |
| 7 | H.G. FUSE | .001 | .002 | .003 |
| 8 | STATION SERVICE TRANS FORMER. | .015 | .02 | .03 |
| 9 | L.T. Distribution BOX. | .002 | .002 | .002 |




1. LIGHTNING ARRESTOR 2. A.B. SWITCH 3. H.G. FUSE 4. CAPACITOR BANK.
5. STATION SERVICE TRANSFORMER 6. L.T. DISTRIBUTION BOX WITH FUSE.

MINI HYDRO POWER PROJECT
ESMAP STUDY

STANDARDISED ELECTRICAL SYSTEM LAYOUT

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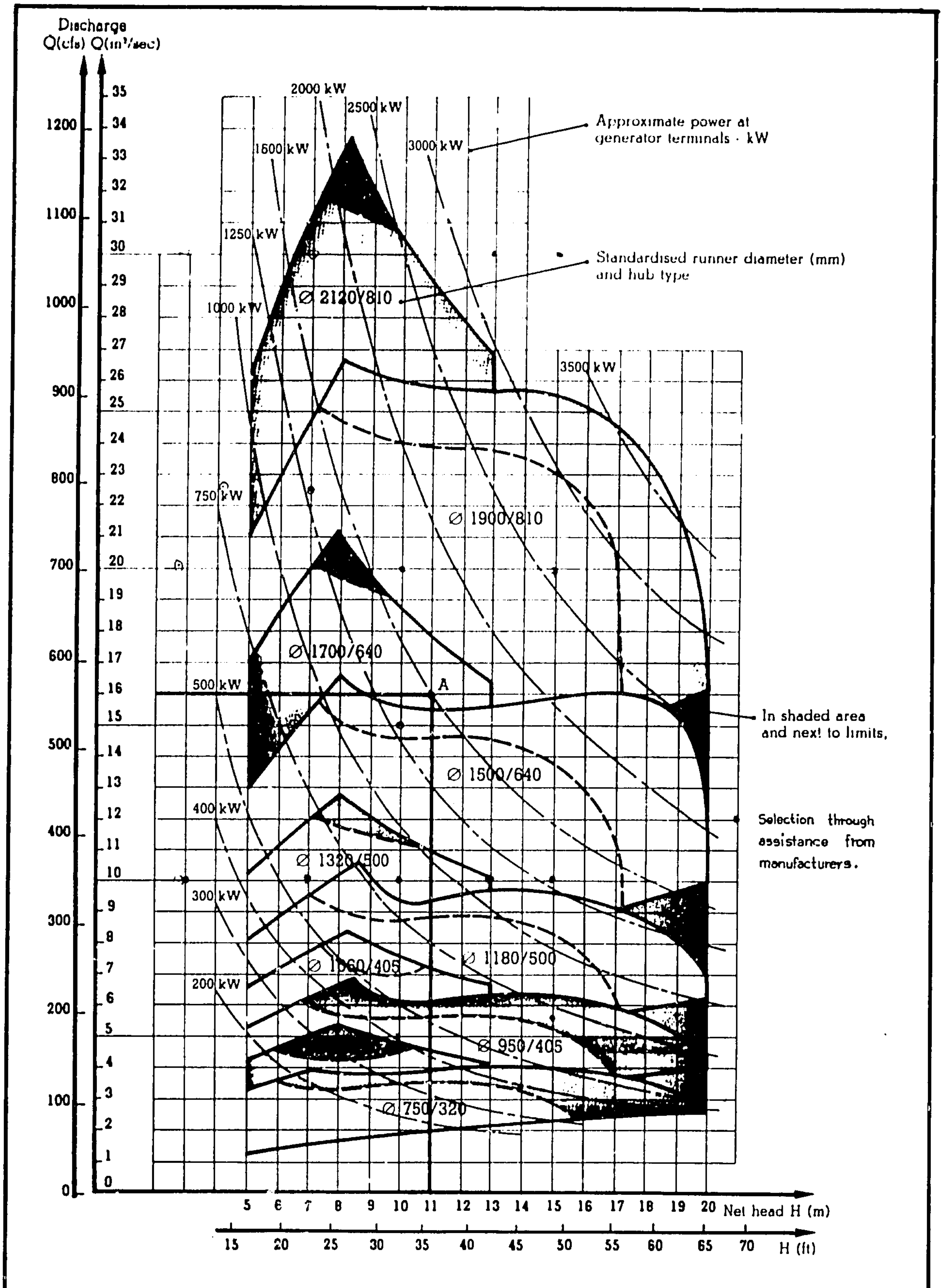



MINI HYDRO POWER PROJECT

ESMAP STUDY

TURBINE SELECTION FOR RANGE
200 kW – 3500 kW.

# ANNEX E

## SAMPLE COST ESTIMATES FOR CIVIL WORKS COMPONENT OF BRINDAVAN SCHEME

## ANNEX E: SAMPLE COST ESTIMATES FOR CIVIL WORKS COMPONENT OF BRINDAVAN SCHEME

**Table E1: Brindavan Dam Scheme - Civil Works Cost**
**(in Rs million)**

| Item | Description of Work | Cost |
|---|---|---|
| 1. | Excavation | 0.033 |
| 2. | Concrete | 0.514 |
| 3. | Steel | |
| | a) Reinforcement | 0.298 |
| | b) Structural Steel | 0.654 |
| 4. | Other Items and Miscellaneous | 2.701 |
| | Total | 4.200 |

A summary of the civil works costs based on project components are given below.

**Table E2: Brindavan Dam Scheme - Civil Works Costs**
**by Project Component in Rs Millions**

| Item | Project Component | | Cost |
|---|---|---|---|
| 1. | Approach pipe (RCC) & Penstock | | 0.43 |
| 2. | Power House | | 0.67 |
| 3. | Tail Race & Auxiliaries | 2.17 | |
| | a) Draft Tube | | (0.5) |
| | b) Tail Race | | (0.07) |
| | c) Regulators | | (1.6) |
| 4. | Others | | 0.93 |
| | a) Preliminary works | | (0.15) |
| | b) Temporary Sheds | | (0.1) |
| | c) T & P at 1 % | | (0.035) |
| | d) Maintenance Charges at 1 % | | (0.035) |
| | e) Establishment Charges at 8 % | | (0.282) |
| | f) Miscellaneous at 5 % | | (0.176) |
| | g) Vehicles, etc | | (0.1) |
| | h) Rounding Off | | (0.052) |
| | Total | | 4.200 |

The details of penstock, powerhouse, tail race including draft tube, and regulators and preliminaries are shown in Table 4, 5, 6, 7, 8 and 9 respectively

**Table E3: Brindavan Dam Scheme - Approach Pipe and Penstock Costs**
**(in Rs million)**

| Item | Work | Unit | Quantity | Rate | Cost |
|---|---|---|---|---|---|
| 1. | Preparation of surface including bending, cleaning, chiseling, etc | Sqm | 35 | 13.2 | 0.0005 |
| 2. | Providing and laying M 20 cc mix with 20 mm and down size aggregates for approach pipes (RCC) including mixing, laying, vibrating, curing, etc | Cum | 39.12 | 905.35 | 0.035 |
| 3. | Providing and reinforcement including fabrication charges etc., complete for item 2 | Tonnes | 3.1 | 8843.6 | 0.027 |
| 4. | Providing and fixing penstock pipes including fabrication charges | Tonnes | 11.79 | 25000 | 0.295 |
| 5. | Providing and laying M 20 cc mix with 20 mm MSA for covering the penstock pipes including mixing, laying, vibrating, curing, etc | Cum | 29.64 | 905.35 | 0.027 |
| 6. | Providing and fixing reinforcement including fabrication charges for item 5 | Tonnes | 2.33 | 8843.6 | 0.021 |
| 7. | Contingencies at 3 % | | | | 0.013 |
| 8. | Work charged establishment at 2 % and rounding off | | | | 0.010 |
| | Total | | | | 0.428 |

**Table E4: Brindavan Dam Scheme - Power House Costs**
**(in Rs million)**

| Item | Work | Unit | Quantity | Rate | Cost |
|---|---|---|---|---|---|
| 1. | Preliminaries such as surveys, setting out, etc | Lump Sum | | | 0.010 |
| 2. | Excavation in hard rock | Cum | 12.35 | 78.2 | 0.010 |
| 3. | Preparation of surface including benching, cleaning, chiseling, etc | Sqm | 123.5 | 13.2 | 0.002 |
| 4. | Providing dowel rods including drilling rods | Rmt | 60 | 92.8 | 0.006 |
| 5. | Providing and laying M 20 cc mix with 20 mm MSA for covering the penstock pipes including mixing, laying, vibrating, curing, etc | Cum | 60.8 | 824.28 | 0.050 |
| 6. | Providing and laying M 20 cc mix with 20 mm MSA including mixing, laying, vibrating, curing, etc complete for walls and beams | Cum | 166.09 | 905.35 | 0.150 |
| 7. | Providing and laying M 20 cc mix with 20 mm MSA for roof slabs including mixing, laying, vibrating, curing, etc for roof slab | Cum | 38.91 | 905.35 | 0.035 |
| 8. | Providing and fixing reinforcement including fabrication charges for item no. 5, 6, and 7. | Tonnes | 22.58 | 8843.6 | 0.200 |
| 9. | Providing and laying mass concrete mix M-15 with 40 mm MSA for filling the place between the units up to the level RL 736.69 m including mixing, laying, vibrating, curing, etc complete | Cum | 143.56 | 750.53 | 0.108 |
| 10. | Providing and fixing rolling shutters of size 3 x 4 m both mechanically and electrically. | Sqm | 12 | 521.6 | 0.006 |
| 11. | Providing and fixing steel windows | Sqm | 6 | 72 | 0.004 |
| 12. | Providing oil painting to PH walls | Sqm | 429.22 | 8.6 | 0.004 |
| 13. | Providing weather proof compound | LS | | | 0.010 |
| 14. | Providing weather proof course over roof slab | Sqm | 121.6 | 49.5 | 0.006 |
| 15. | Water supply and sanitary arrangement to power house | LS | | | 0.020 |
| 16. | Providing drainage arrangements | LS | | | 0.015 |
| 17. | Contingencies at 3 % | | | | 0.019 |
| 18. | Work charged establishment at 2 % | | | | 0.013 |
| 19. | Rounding off | | | | 0.002 |
| | Total | | | | 0.669 |

**Table E5: Brindavan Dam Scheme - Draft Tube Costs**
**(in Rs million)**

| Item | Work | Unit | Quantity | Rate | Cost |
|---|---|---|---|---|---|
| 1. | Excavation in hard rock | Cum | 171 | 78.2 | 0.013 |
| 2. | Providing and fixing draft tube steel pipes including fabrication charges | Tonne | 14.37 | 25000 | 0.359 |
| 3. | Providing and laying RCC draft tube pipes up to gate structure using CC, M-20,20 mm MSA including mixing, vibrating, curing, etc | Cum | 26.88 | 905.35 | 0.024 |
| 4. | Providing and laying concrete covering for steel draft tube pipes using M-20, CC mix | Cum | 36.3 | 905.35 | 0.033 |
| 5. | Providing and fixing reinforcement including fabrication charges for item no. 3 and 4. | Tonne | 4.96 | 8843.6 | 0.044 |
| 6. | Contingencies at 3 % | | | | 0.014 |
| 7. | Work charged establishment at 2 % | | | | 0.009 |
| 8. | Rounding off | | | | 0.004 |
| | Total | | | | 0.501 |

**Table E6: Brindavan Dam Scheme - Tail Race Costs**
**(in Rs million)**

| Item | Work | Unit | Quantity | Rate | Cost |
|---|---|---|---|---|---|
| 1. | Excavation in hard rock | Cum | 123.5 | 78.2 | 0.010 |
| 2. | Preparation of surface including binding, | Sqm | 120 | 13.2 | 0.002 |
| 3. | Providing M-20,20 mm MSA for tail race bed concrete including mixing, vibrating,laying, curing, etc | Cum | 57 | 905.35 | 0.052 |
| 4. | Contingencies at 3 % | | | | 0.002 |
| 5. | Work charged establishment at 2 % | | | | 0.001 |
| 6. | Rounding off | | | | 0.003 |
| | Total | | | | 0.069 |

**Table E7: Brindavan Dam Scheme - Regulators Costs**
**(in Rs million)**

| Item | Work | Unit | Quantity | Rate | Cost |
|---|---|---|---|---|---|
| 1. | Providing and fixing tail race gate including gentry crane and erection | Cum | 1 | 1500000 | 1.500 |
| 2. | Contingencies at 3 % | | | | 0.05 |
| 3. | Work charged establishment at 2 % and rounding off | | | | 0.031 |
| | Total | | 1.581 | | |

**Table E8: Brindavan Dam Scheme - Preliminary Works Costs**
**(in Rs million)**

| Item | Work | Cost |
|---|---|---|
| 1. | Surveys | 0.025 |
| 2. | Hydrological and Meteorological investigations | 0.025 |
| 3. | Testing of materials | 0.025 |
| 4. | Printing project reports, estimates, etc | 0.025 |
| 5. | Vehicles for inspecting officers | 0.02 |
| 6. | Surveys and Mathematical instruments | 0.02 |
| 7. | Miscellaneous and unforeseen expenditures | 0.01 |
| | Total | 0.15 |

For the canal-based mini hydro schemes Maddur civil works cost estimates are given as examples in Table 10 and 11.

**Table E9: Maddur Canal Civil Works Costs Estimate**
**(in Rs million)**

| Item | Work | Maddur Alt.II | | Maddur Alt.I | | KPC Proposal (1990) | |
|---|---|---|---|---|---|---|---|
| | | Quantity | Cost | Quantity | Cost | Quantity | Cost |
| 1. | Excavation | | | | | | |
| | a) Soil M3 | 30000 | 1.227 | 30000 | 1.227 | 4000 | 1.672 |
| | b) Rock M3 | 5500 | 0.521 | 5500 | 0.521 | 29000 | 2.749 |
| 2. | Concrete | | | | | | |
| | a) M15 M3 | 1420 | 1.015 | 1420 | 1.015 | 3000 | 2.145 |
| | b) M20 M3 | 120 | 0.11 | 120 | 0.11 | 140 | 0.129 |
| 3. | Steel | | | | | | |
| | a) Reinforcement T | 25 | 0.26 | 25 | 0.26 | 23 | 0.24 |
| | b) Structural T | 1 | 0.013 | 1 | 0.013 | 1 | 0.013 |
| 4. | Embankment M3 | 31500 | 0.882 | 31500 | 0.882 | 13200 | 0.37 |
| 5. | Miscellaneous L.S | - | 0.936 | - | 0.936 | - | 5 |
| 6. | Water Conductor System | | 2.37 | | 6.265 | - | - |
| | Total | | 7.334 | | 11.229 | | 12.318 |

**Table 11: Maddur Scheme: Civil Works Costs by Project Component**
**(n Rs million)**

| ESMAP Alternatives | Intake Structure | Penstock | Powerhouse | Tailrace | Total |
|---|---|---|---|---|---|
| Alt.1 Precast Home Pipe(200 m) | 2.7 | 8.3 | 0.48 | | 11.48 |
| Alt.2 Cast in Sita Trough (300 m) | 2.7 | 3.9 | 0.48 | | 7.08 |
| Alt.3 Cast in Sita Trough (100 m) | 2.7 | 1.95 | 0.48 | 10.6 | 15.73 |
| Alt.4 Precast Home Pipe(100 m) | 2.7 | 4.15 | 0.48 | 10.6 | 17.93 |
| Alt.5 Open Tunnel with Embankment | 2.7 | 3.1 | 0.74 | 10.6 | 17.14 |

# ANNEX F

## LIST OF LOCAL MANUFACTURERS OF MINI-HYDRO PLANT IN INDIA

## ANNEX F: LIST OF LOCAL MANUFACTURERS OF MINI-HYDRO PLANT IN INDIA

### A. Types of Turbines

1) **Syphon**: Tubular with syphon intake, turbine above tail water level and no gate or valve. Head restricted to 5 meters. For heads above 5 meters and up to 30 meters, syphon intake with extended penstock, setting below tail water level. Powerhouse - conventional.

2) **Vertical Kaplan**: Propeller with radial wicket gate configuration. Control system designed so that variation in blade angle is coupled with the wicket gate setting. Speed increaser provided.

3) **Francis**: Radial (low specific speed) and mixed flow types (peak efficiency at considerably higher specific speed).

4) **Cross Flow**: impulse turbine with partial arc admission conical draft tube. Flat efficiency curve for a range of 1/3 to full flow.

5) **Propeller**: Fixed blade with or without provision of manual adjustment of blades. Components include wicket gates, runner and draft tube. Blade adjustment, if provided, for 40-105% rated flow.

6) **Tubular (upstream elbow)**: Generator outside and upstream of turbine. Connected through speed increaser. Blades fixed or adjustable (semi-kaplan). No wicket gates, shut off/start up valve or gate required.

7) **Tubular (bulb)**: Generator within bulb directly connected or through epicyclic or planetary gears. Fixed or adjustable blades. Two variations to this type are rim type (generator rotor mounted on the periphery of turbine runner blades); Lip seal design limited to 15 meter head with runner dia 3.5 m). Fixed blades and capacity up to 2,000 kw. Escher Wyss design for higher heads and capacity or externally mounted right angle drive generator.

### B. Manufacturers by Location in India

#### DELHI

1. Flovel Private Ltd.
A-219, Okhla Industrial Area
Phase-I
New Delhi-110 020

2. M/s. Triveni Engineering Works Ltd.
Projects & Engineering Division
B-65, Okhla Industrial Area, Phase-I
New Delhi-110 020

GUJARAT

3. Jyoti Limited
Industrial Area
F.O. Chemical Industries
Vadodara-390 003

KARNATAKA

4. Foress Engineering (India Pvt. Ltd.)
Peenya Industrial Estate
desarhalli
Bangalore

5. Tungabhadra Steel Products Ltd.
Tunga Bhadra dam
Karnataka-583 225

KERALA

6. M/s. Steel Industries Kerala Ltd.
Jupiter Building Complex
Post box No. 807, M.G. Road
Trichur-680 004
Kerala

MADHYA PRADESH

7. Bharat Heavy Electrical Ltd
Piplani
Bhopal

PUNJAB

8. Punjab Power Generation Machines Ltd.
SCO 108 & 109
Sector 8-C
Chandigarh-160 018

TAMIL NADU

9. Best & Crompton
Small Hydel Project Division
39, Industrial Estate (North)
Ambattur, Madras-600 098

WEST BENGAL

10. Larsen & Toubro Ltd.
3 B, Shakesphere Sarani
P.O. Box 619
Calcutta-700 071

C. I.C. Engines with Alternative Fuels

MAHARASHTRA

1. Crompton Greaves Ltd.
Kanjur
Bhandup
Bombay-400 078

2. Kirloskar Oil Engines Ltd.
13, Laxmanrao Kirloskar Road
Khadki
Pune-411 003

UTTAR PRADESH

3. Sterling Machine Tools
B-13, Foundry Nagar
Hathras Road
Agra-282 006

D. Battery Powered Vehicles

MADHYA PRADESH

1. Bharat Heavy Electricals Ltd.
P.O. Piplani
Bhopal-462 022

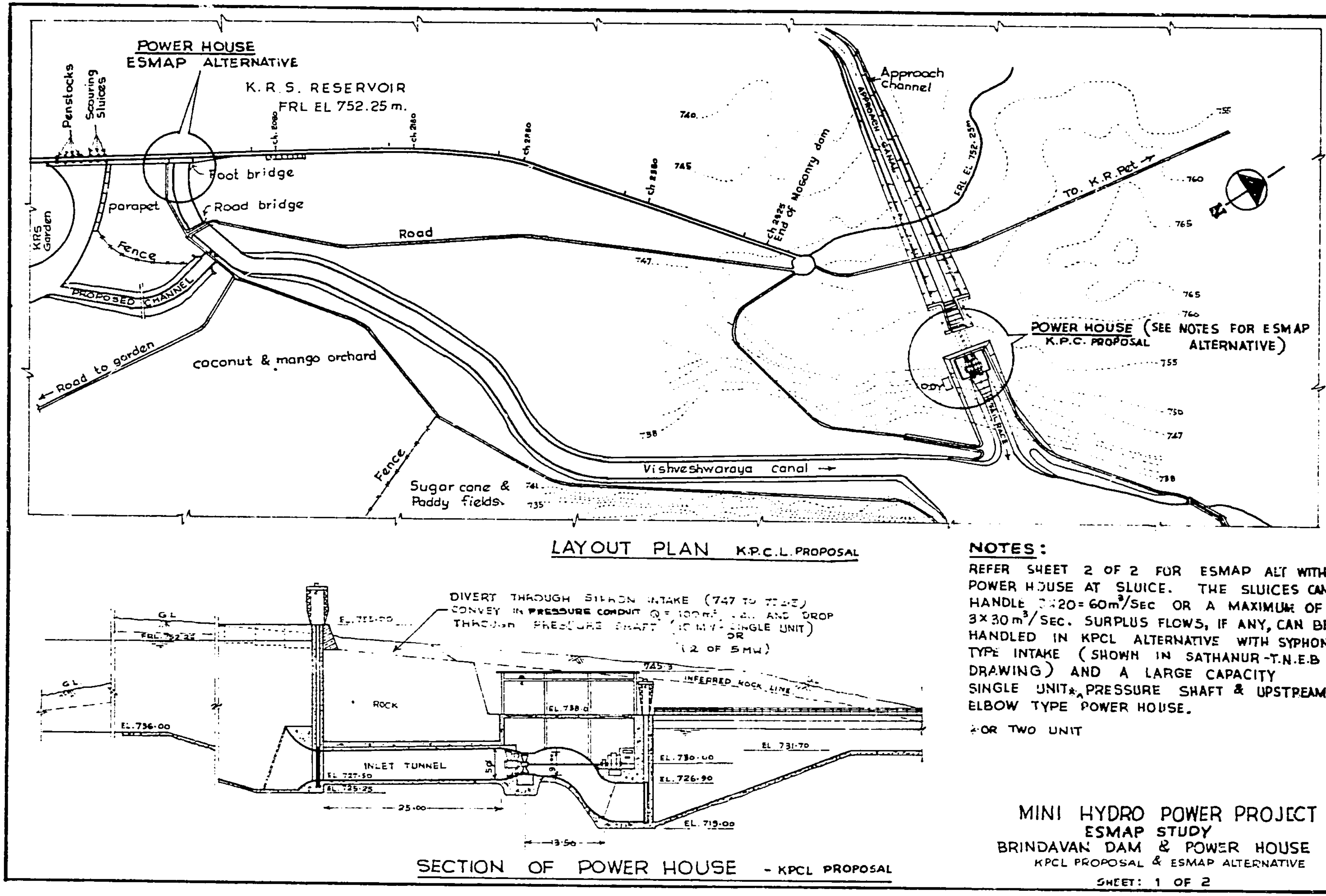
MAHARASHTRA

2. M/s. Chatabe Vehicles (India) Ltd.
"Sadguru", 16-French Bridge Road
Chowpalty, Bombay-400 007

## ANNEX G

## TECHNICAL DRAWINGS FOR CASE STUDY SCHEMES

1. Brindavan Dam Scheme, Karnataka
2. Maddur Canal Drop Scheme, Karnataka
3. Kilara Canal Drop Scheme, Karnataka
4. Guntur Branch Canal Scheme, Andhra Pradesh
5. Kuttiyadi Tailrace Scheme, Kerala
6. Tugal Canal Drop Scheme, Punjab
7. Lower Bhavani Dam Scheme, Tamil Nadu

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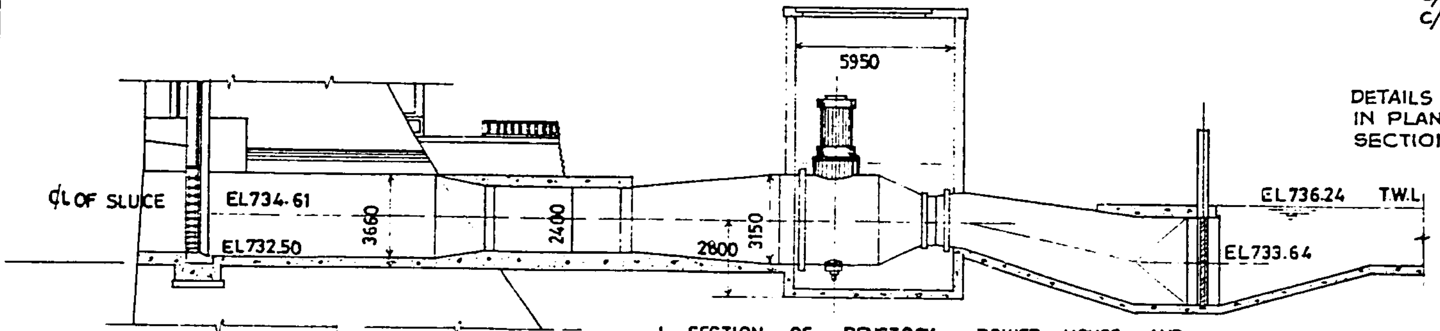
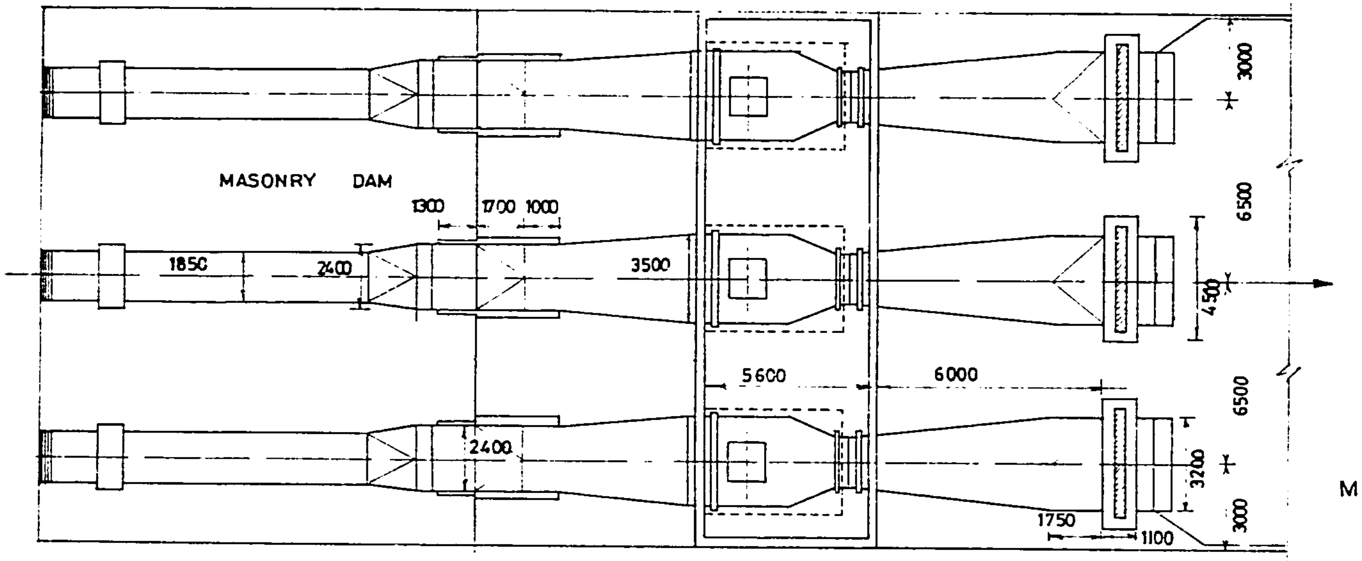
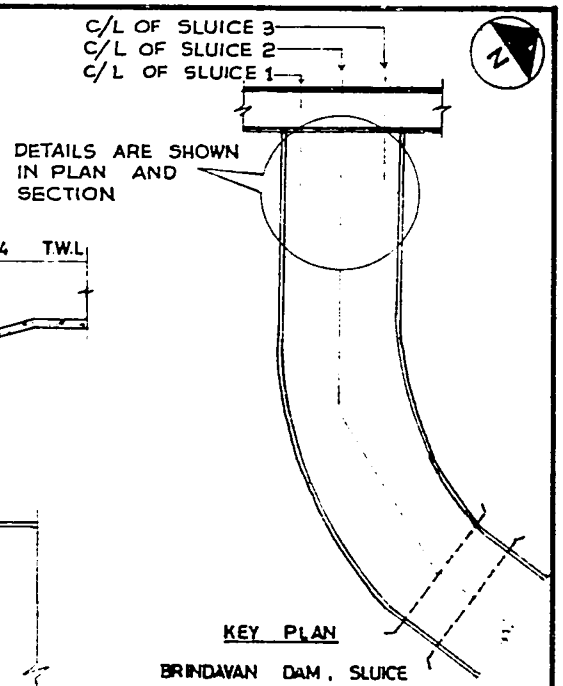



L-SECTION OF PENSTOCK, POWER HOUSE AND DRAFT TUBE




PLAN OF POWER HOUSE



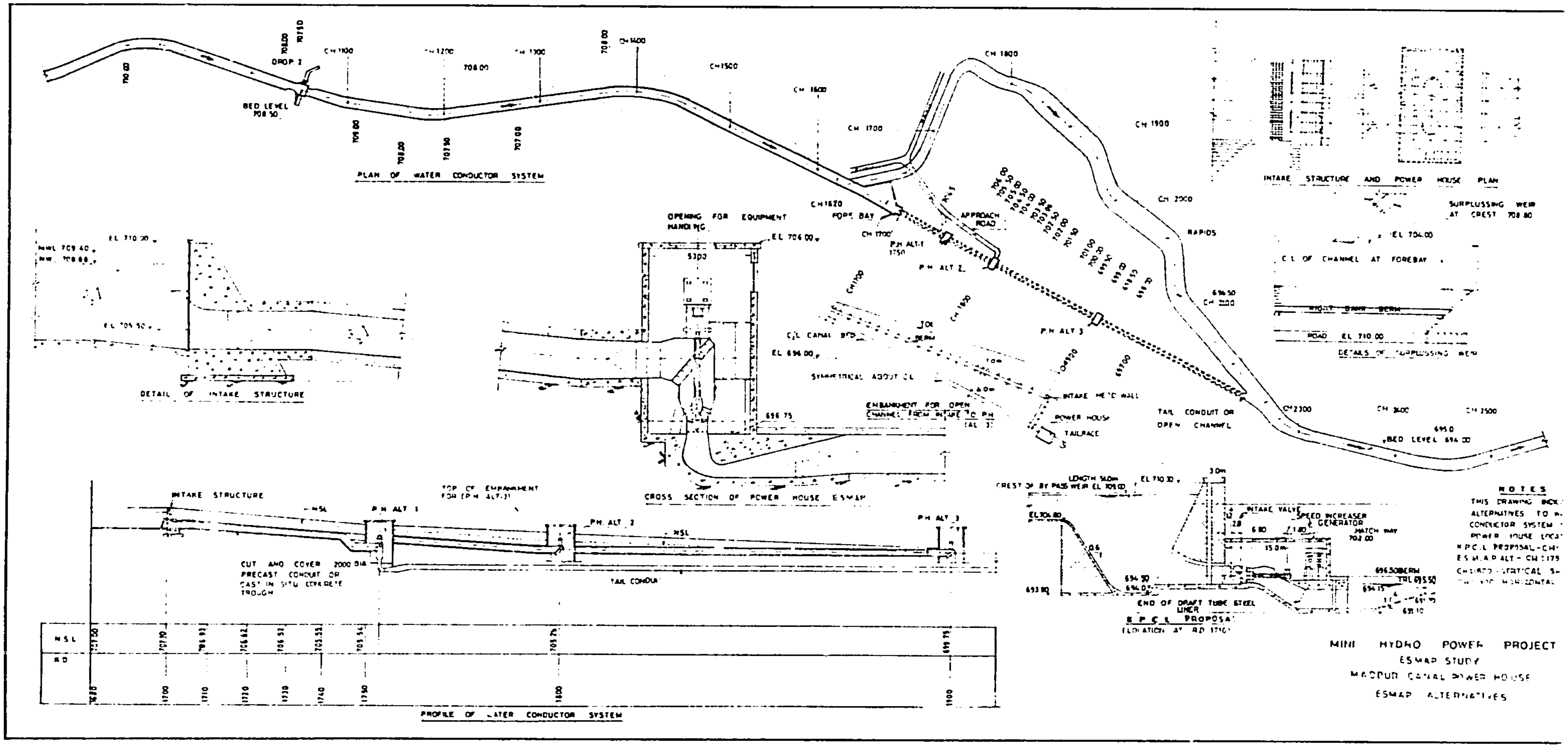

KEY PLAN

BRINDAVAN DAM, SLUICE AND POWER HOUSE

MINI HYDRO POWER PROJECT
ESMAP STUDY
BRINDAVAN DAM AND POWER HOUSE
ESMAP ALTERNATIVES

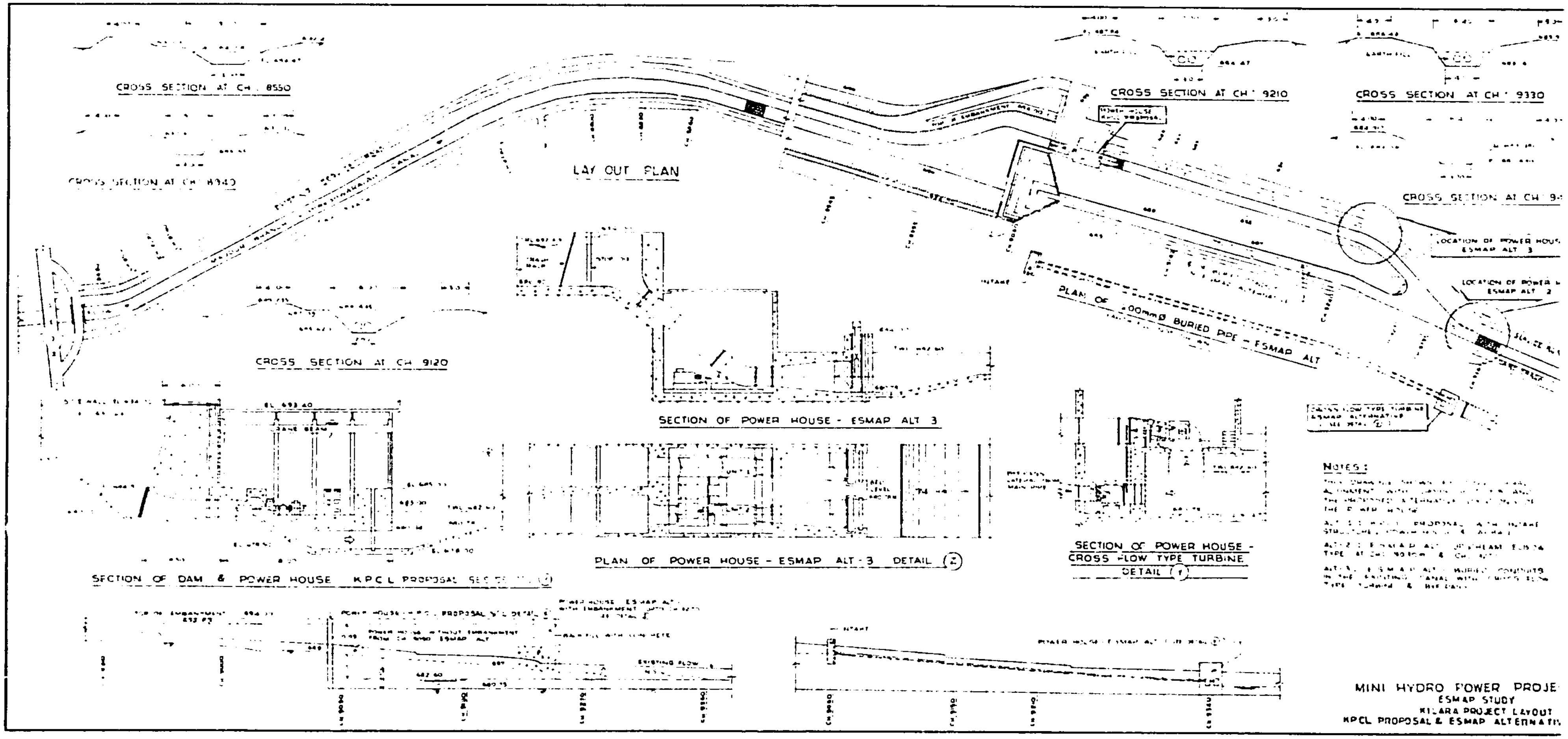
SHEET 2 OF 2

85

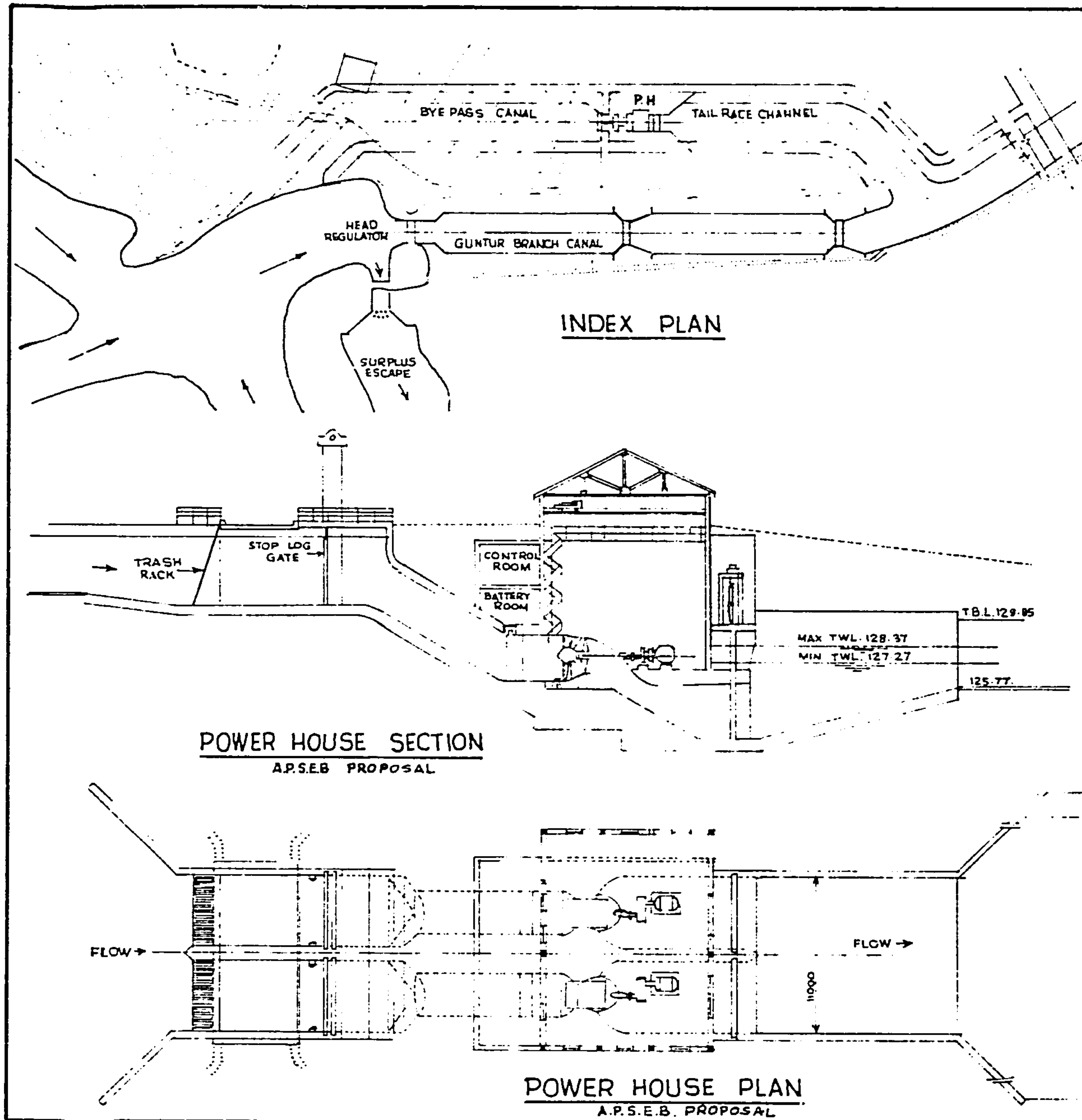


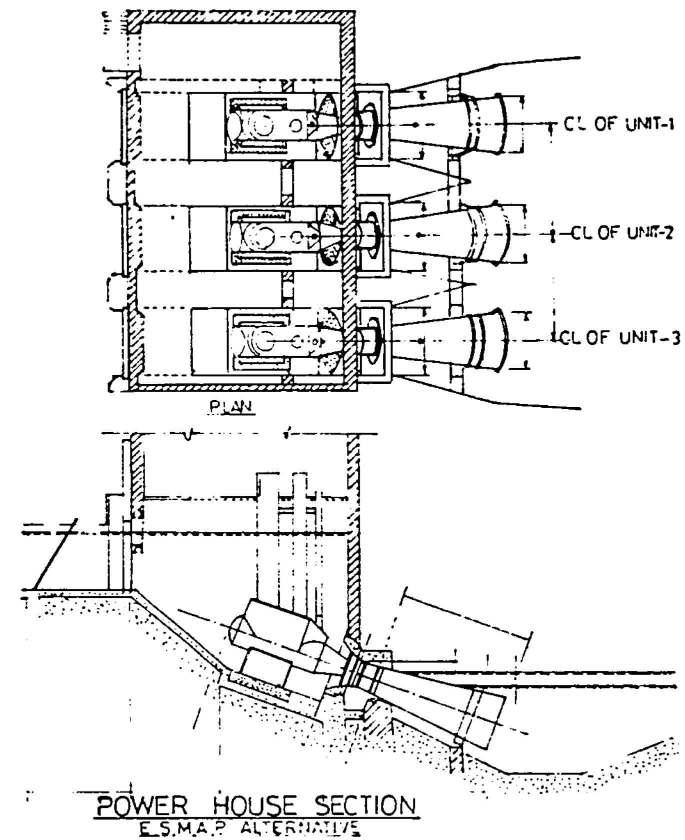

sads/w48595(98)

.86 -




sadaw48595(99)




NOTES:

ESMAP ALTERNATIVE IS WITH A HIGH LEVEL APPROACH CHANNEL AND A TROUGH TYPE (UPSTREAM ELBOW) POWER HOUSE. THE APSEB DESIGN NEEDS REVIEW DUE TO FUTURE RISE IN FRL BY ABOUT 2.5m AS PER DRAWING FOR REGULATOR IN PROJECT REPORT.

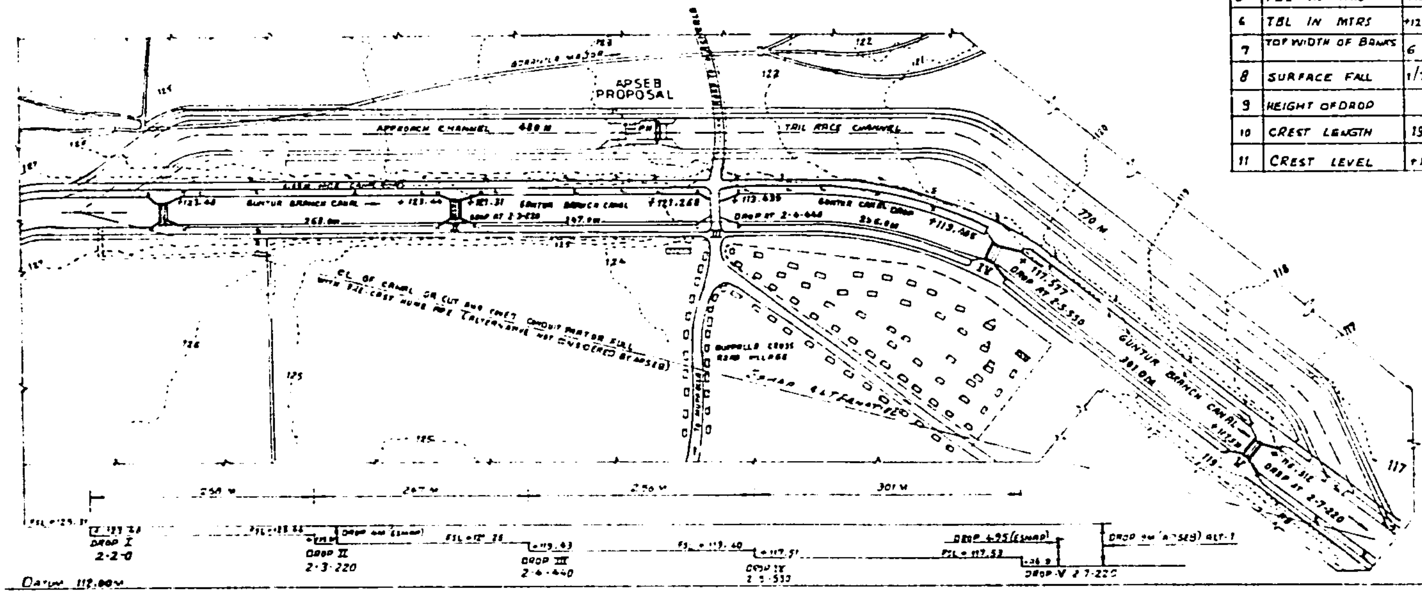
MINI HYDRO POWER PROJECT
ESMAP STUDY
GUNTUR CANAL - I
POWER HOUSE
APSEB PROPOSAL & ESMAP ALTERNATIVE
SHEET:

## HYDRAULIC PERTICULARS  n = 0.0225

| SL NO | PERTICULARS | I DROP AT MILE-2-F 2-00' u/s | I DROP AT MILE-2-F 2-00' D/s | II DROP AT MILE 2-F3-220' u/s | II DROP AT MILE 2-F3-220' D/s | III DROP AT MILE 2-F4-440' u/s | III DROP AT MILE 2-F4-440' D/s | IV DROP AT MILE 2-F5-550' u/s | IV DROP AT MILE 2-F5-550' D/s | V DROP A[illegible] MILE 2-F 7-2[illegible] u/s | V DROP A[illegible] MILE 2-F 7-2[illegible] D/[illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | DESIGNED DISCHARGE IN CUSECS | 3440 | 344C | 3440 | 3440 | 3440 | 3440 | 3440 | 3440 | 3440 | 34[illegible] |
| 2 | BED FALL IN MTRS | +125.312 | +132.483 | +123.447 | +121.313 | +121.268 | +119.439 | +119.485 | +117.577 | +117.531 | +116[illegible] |
| 3 | BED WIDTH | 28.346 | 28.346 | [illegible].346 | 28.346 | 28.346 | 28.346 | 28.346 | 28.346 | 28.346 | 28[illegible] |
| 4 | FSD IN MTRS | 3.17 | 3.17 | 3.17 | 3.17 | 3.17 | 3.17 | 3.17 | 3.17 | 3.17 | 3[illegible] |
| 5 | FSL IN MTRS | +128.482 | +126.653 | +126.617 | +124.483 | +124.444 | +122.601 | +122.575 | +120.746 | +120.700 | +11[illegible] |
| 6 | TBL IN MTRS | +129.396 | +127.568 | +127.531 | +125.398 | +125.352 | +123.523 | +123.490 | +121.661 | +121.615 | +12[illegible] |
| 7 | TOP WIDTH OF BANKS | 6.096/3.657 | | 6.096/3.657 | | 6.096/3.657 | | 6.096/3.657 | | 6.096/3.65[illegible] | |
| 8 | SURFACE FALL | 1/7000 | 1/7000 | 1/7000 | 1/7000 | 1/7000 | 1/7000 | 1/7000 | 1/7000 | 1/7000 | 1/[illegible] |
| 9 | HEIGHT OF DROP | 1.82[illegible] | | 2.134 | | 1.829 | | 1.829 | | 1.219 | |
| 10 | CREST LENGTH | 19.20 | — | 19.20 | — | 19.20 | — | 19.20 | — | 19.20 | |
| 11 | CREST LEVEL | +123.523 | | +123.928 | | DROP CUM RADG BRIDGE | | — | | — | |

NOTES:-

ALL DIMENSIONS ARE IN MILLIMETERS AND ALL ELEVATIO[illegible] IN METERS. THIS DRAWING INDICATES EXISTING DR[illegible] AND PROPOSED BYEPASS CHANNEL FOR MINI HYDEL POWE[illegible] STATION (2 x 2250 kw) ON GUNTUR BYE PASS CHANNEL AND BURRIED CONDUIT ON RIGHT BANK. THE ALTERNATIVE [illegible] PROVIDE 25% SAVINGS IN LENGTH OF CANAL AND HEN[illegible] COSTS. THE TABULATED HYDRAULIC PERTICULARS SHOW DESIGNED DISCHARGE IN THE CANAL AS ABOUT 100 $m^3/s$ WHERE AS THE DURATION CURVE SHOW A MAXIMUM UTILIZATION OF 60 $m^3/sec$ ONLY. HENCE WATER LE[illegible] MAY CHANGE AND CORRESPONDING HEADS TO BE REFIXED [illegible] APSEB. THE CANAL LINING IS DAMAGED AT A FEW LOCA[illegible] SUITABLE ROUGHNESS COEFFICIENT AND INTEGRITY TESTS [illegible] LINING IS REQUIRED.



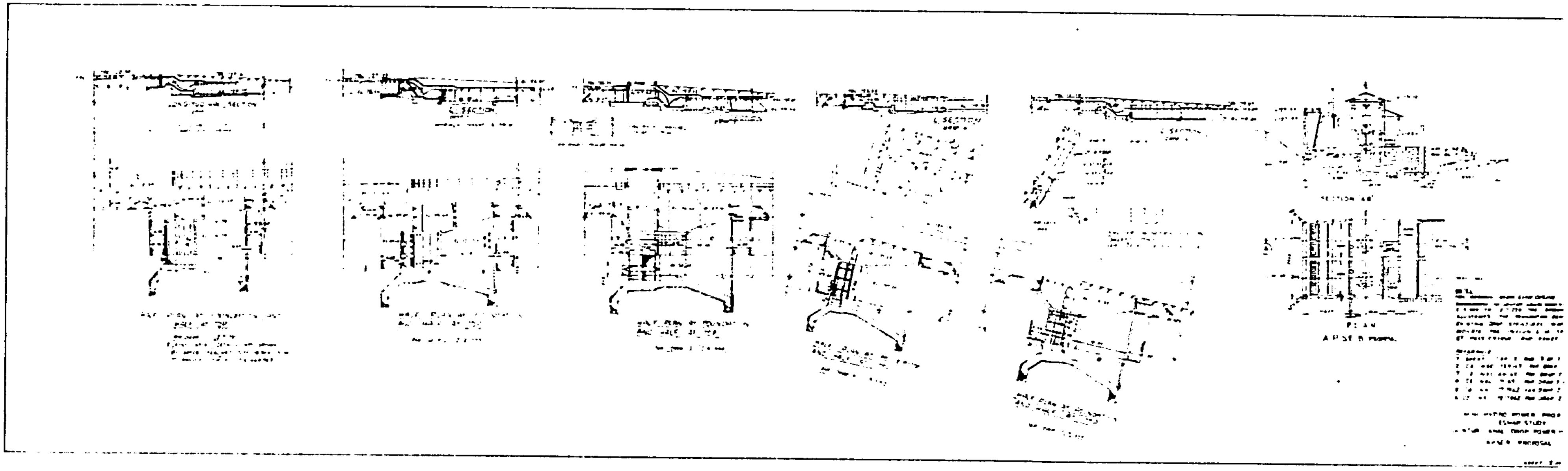

GUNTUR CANAL POWER HOUSE LAYOUT

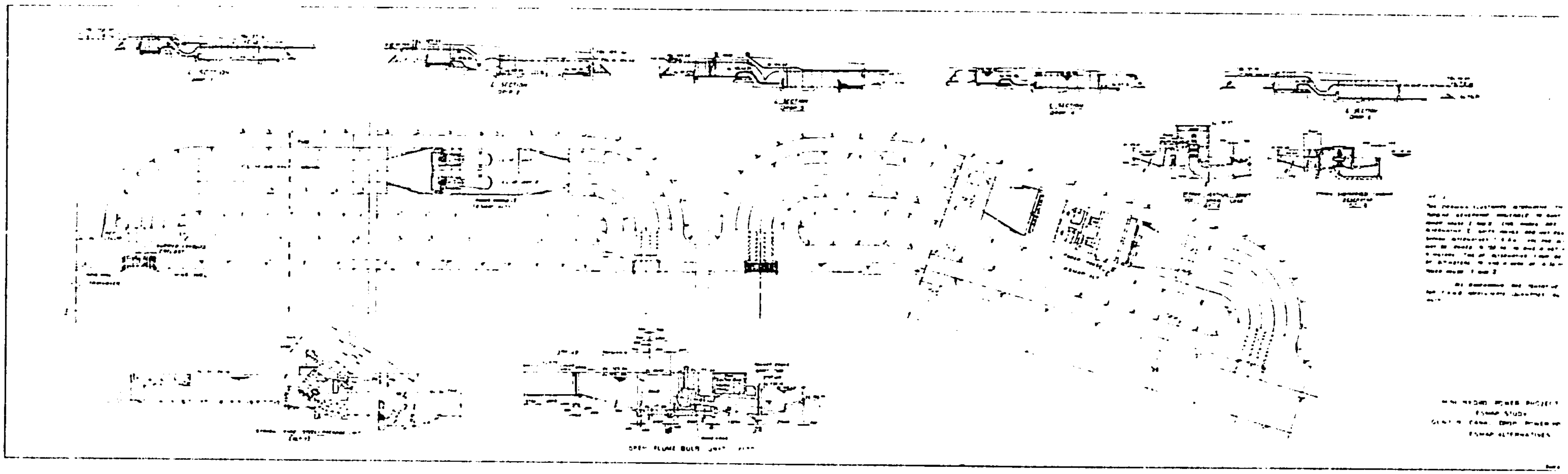
MINI HYDRO POWER PROJECT
ESMAP STUDY
GUNTUR CANAL DROPS FROM 2-2-00 TO 2-7-[illegible]
APSEB PROPOSAL AND
ESMAP ALTERNATIVE LAYOUT

SHEET 1 OF 4

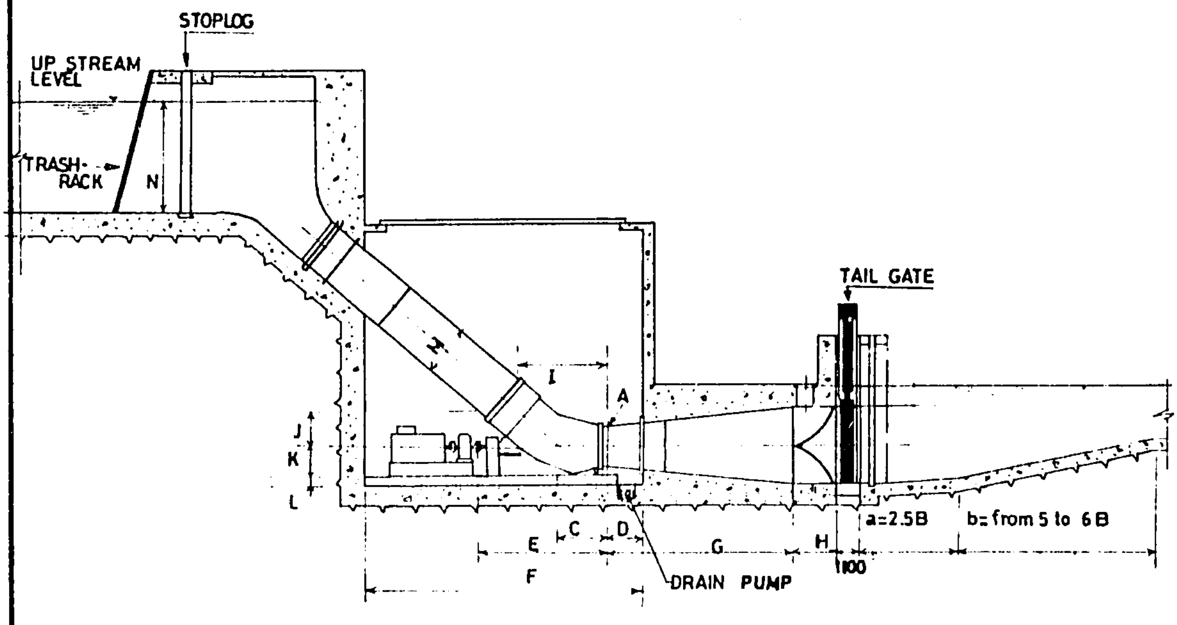
sads/w48505(95)

85 -

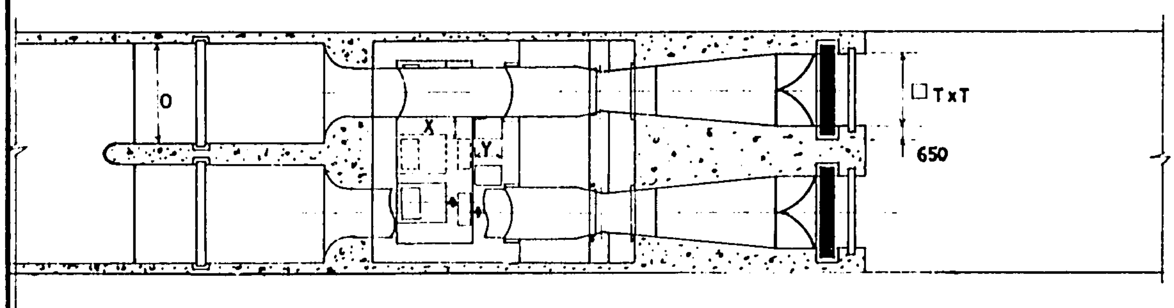




sads/w48595(97)




**SECTION**




**PLAN**

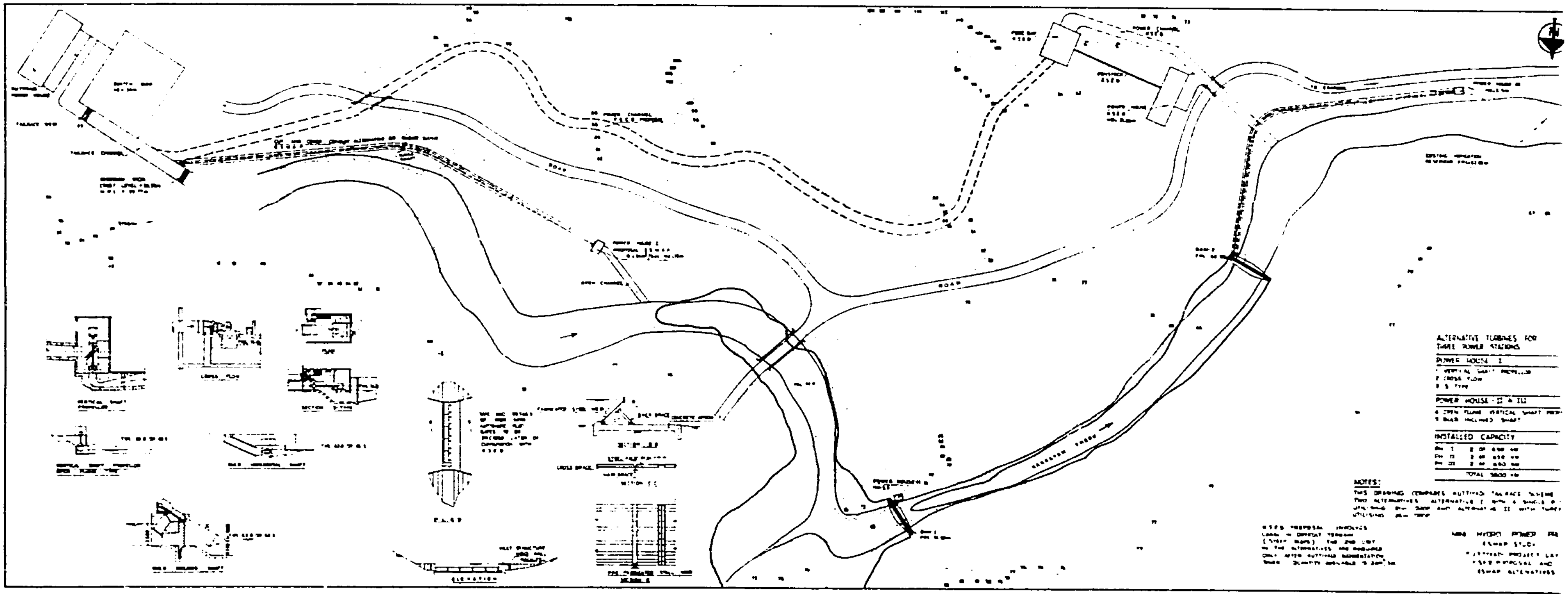
| TYPE OF RUNNER HUB | 640 | 810 |
|---|---|---|
| RUNNER DIAMETER | 1700 | 2120 |
| B | 1700 | 2120 |
| C | 2120 | 2640 |
| D | 1370 | 1720 |
| E | 5115 | 7100 |
| F | 11230 | 15600 |
| G | 7990 | 9960 |
| H | 1810 | 2260 |
| I | 3855 | 4805 |
| J | 1455 | 1820 |
| K | 1245 | 1550 |
| L | 400 | 400 |
| M | 2130 | 2660 |
| M1 | 2720 | 3390 |
| M2 | 2380 | 3000 |
| EL mini | 3230 | 4030 |
| T | 3200 | 4030 |
| X | 1000 | 1000 |
| Y | 1300 | 1300 |
| Z | 2520 | 3135 |

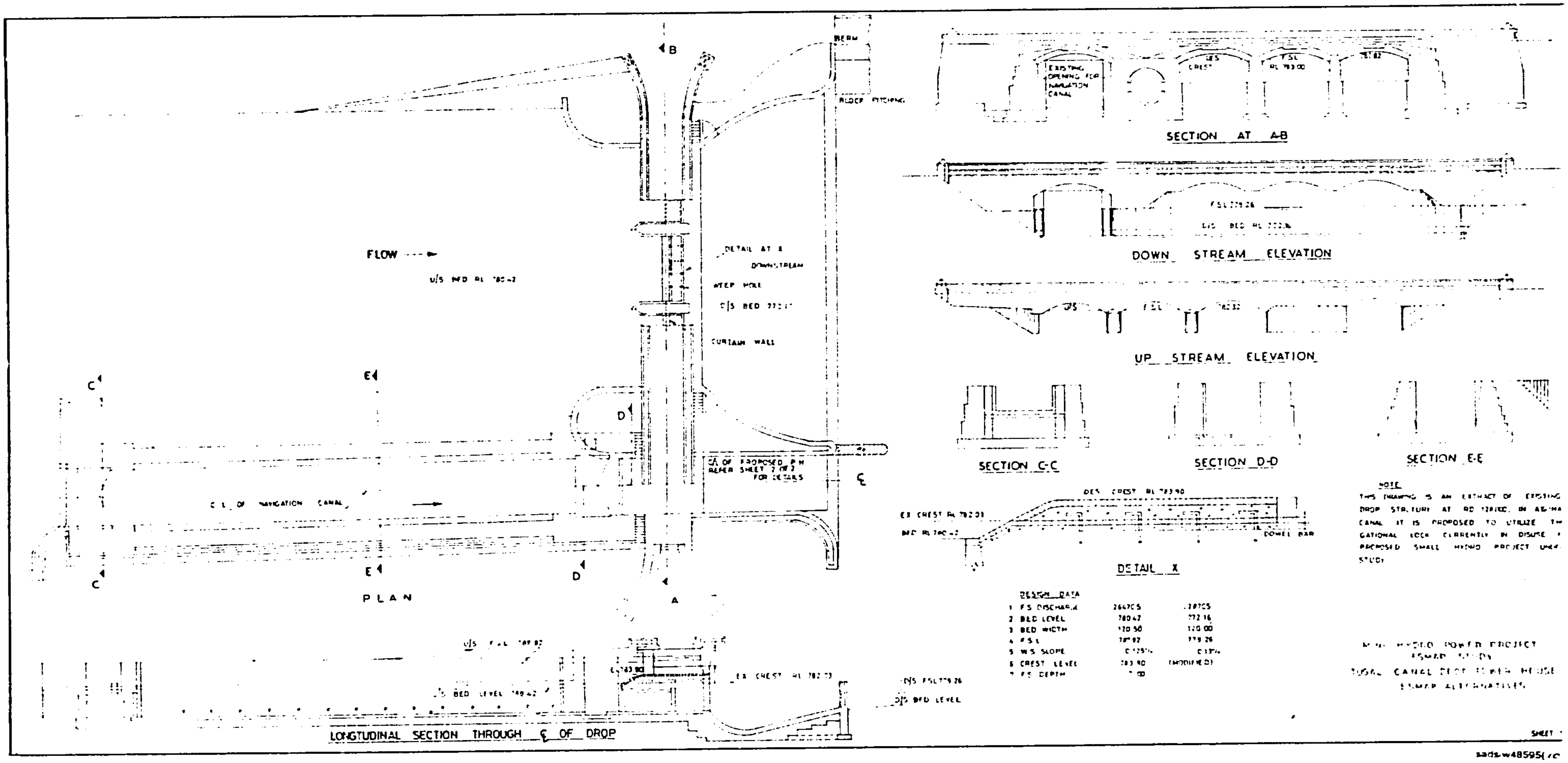
UPSTREAM ELBOW TYPE FOR
1) 8M DROP - 2120 RUNNER DIA
2) 4M DROP - 1700 RUNNER DIA

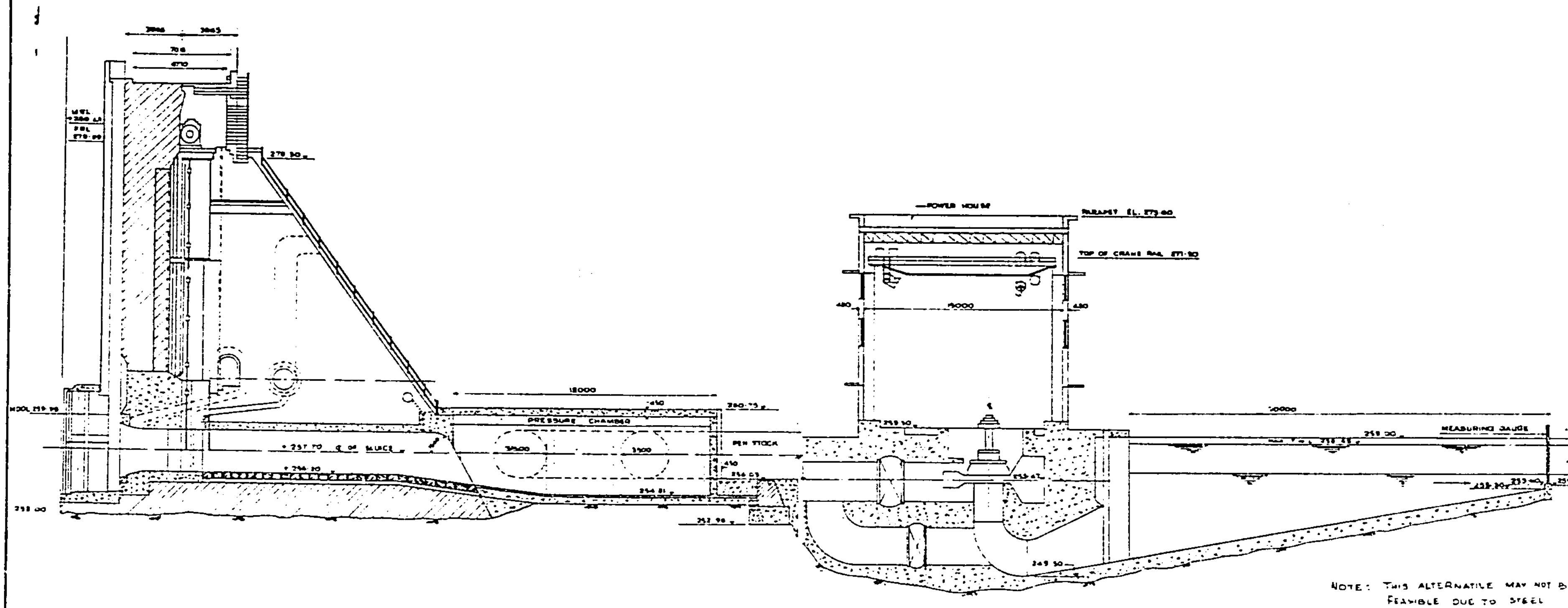
ESMAP ALTERNATIVE '4' OF
APSEB ALTERNATIVE SHOWN IN
SHEETS 1 OF 4 AND 2 OF 4

MINI HYDRO POWER PROJECT
ESMAP STUDY
GUNTUR CANAL
POWER HOUSE PLAN & SECTIONS
ESMAP ALTERNATIVE
SHEET 4 OF 4

92.


ALTERNATIVE TURBINES FOR
THREE POWER STATIONS
POWER HOUSE I
2 CROSS FLOW
POWER HOUSE II & III
INSTALLED CAPACITY
NOTES:
ESHAP STUDY


B
BERM
BLOCK PITCHING
SECTION AT A-B
DOWN STREAM ELEVATION
UP STREAM ELEVATION
FLOW
DETAIL AT X
DOWNSTREAM
WEEP HOLE
CURTAIN WALL
C
E
D
C.L. OF NAVIGATION CANAL
PLAN
A
SECTION C-C
SECTION D-D
SECTION E-E
NOTE
DETAIL X
DOWEL BAR
DESIGN DATA
1 F.S. DISCHARGE 2667CS
2 BED LEVEL 780.42
3 BED WIDTH 120.50
5 W.S. SLOPE
6 CREST LEVEL 783.90 (MODIFIED)
7 F.S. DEPTH
LONGTUDINAL SECTION THROUGH ℄ OF DROP
SHEET
sads-w48595(/c



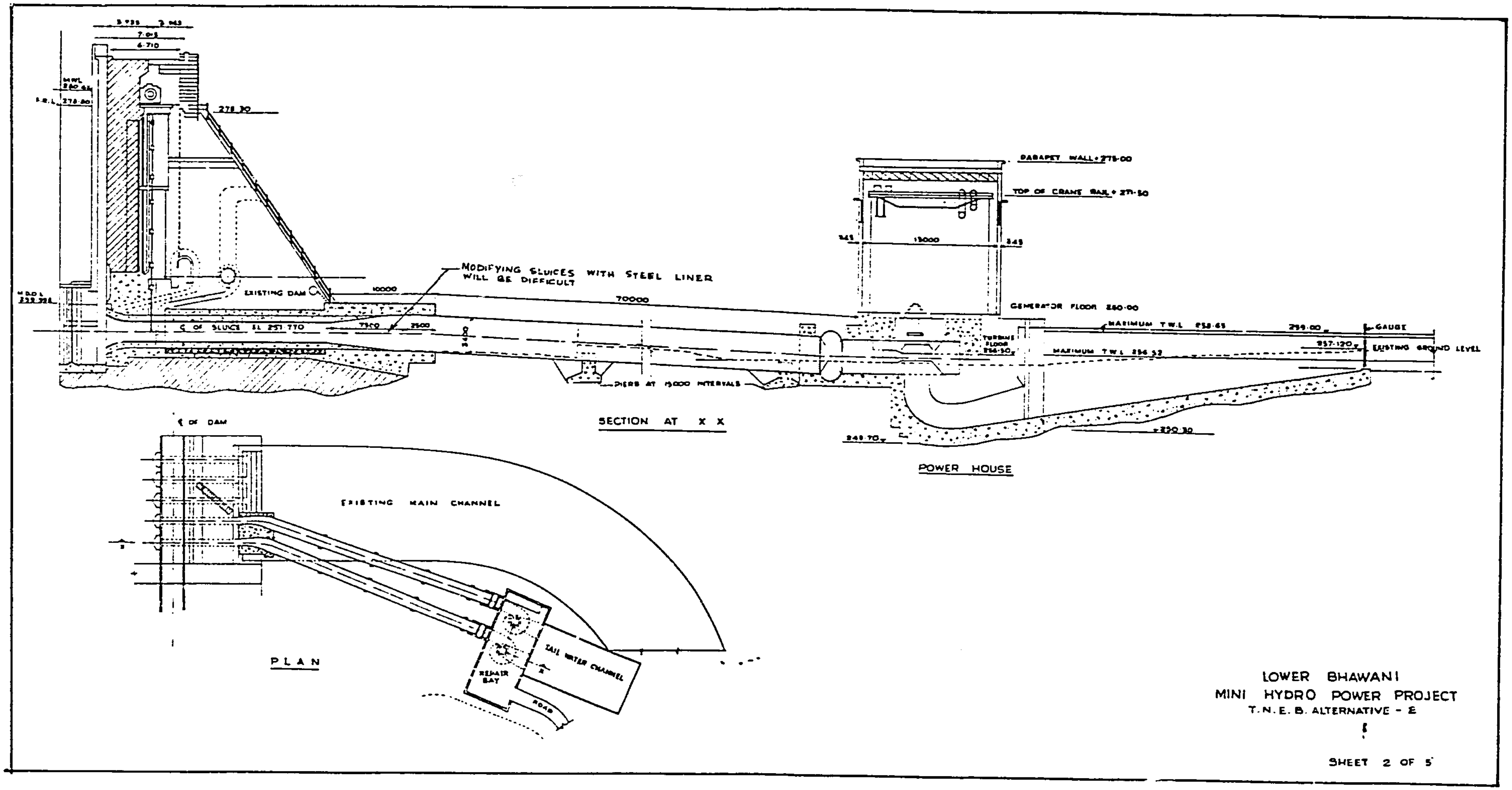

CROSS SECTION

NOTE: THIS ALTERNATIVE MAY NOT BE FEASIBLE DUE TO STEEL ANCHOR BARS REQUIRED TO COUNTERACT PRESSURES FROM RESERVOIR, etc.

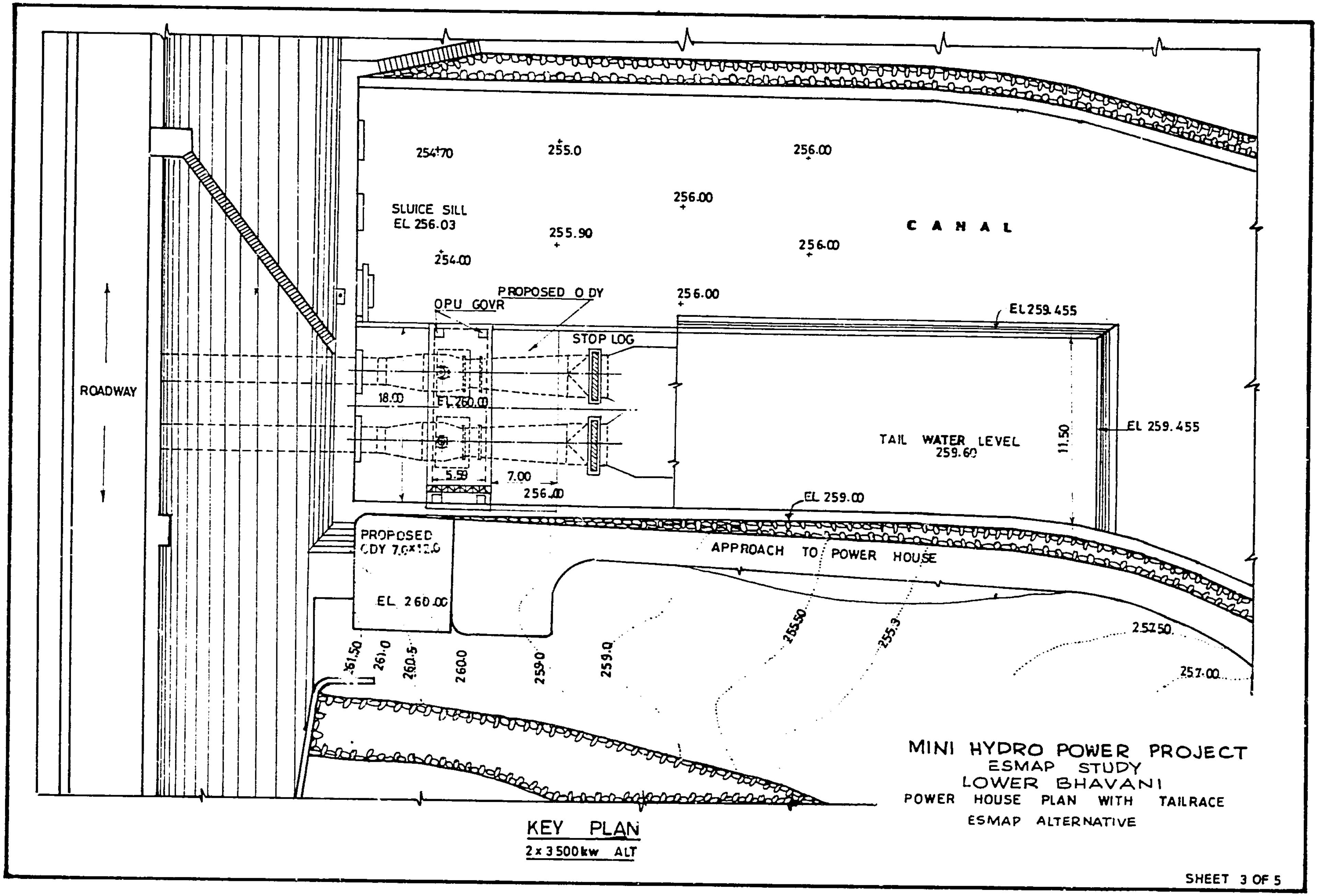
LOWER BHAWANI
MINI HYDRO POWER PROJECT
T N E B ALTERNATIVE - 1

SHEET 1 OF 5

sads/w48595( 76 )

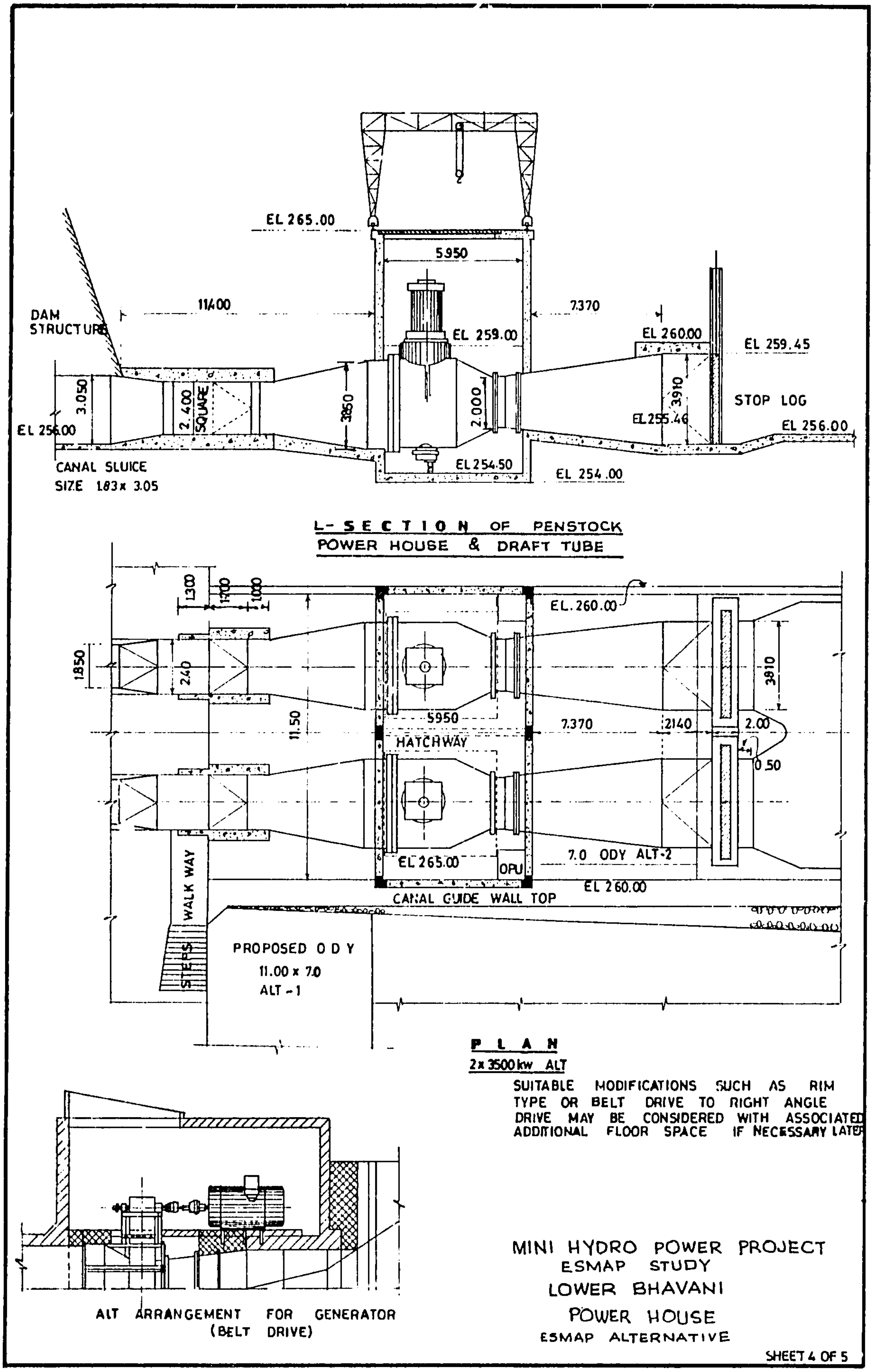


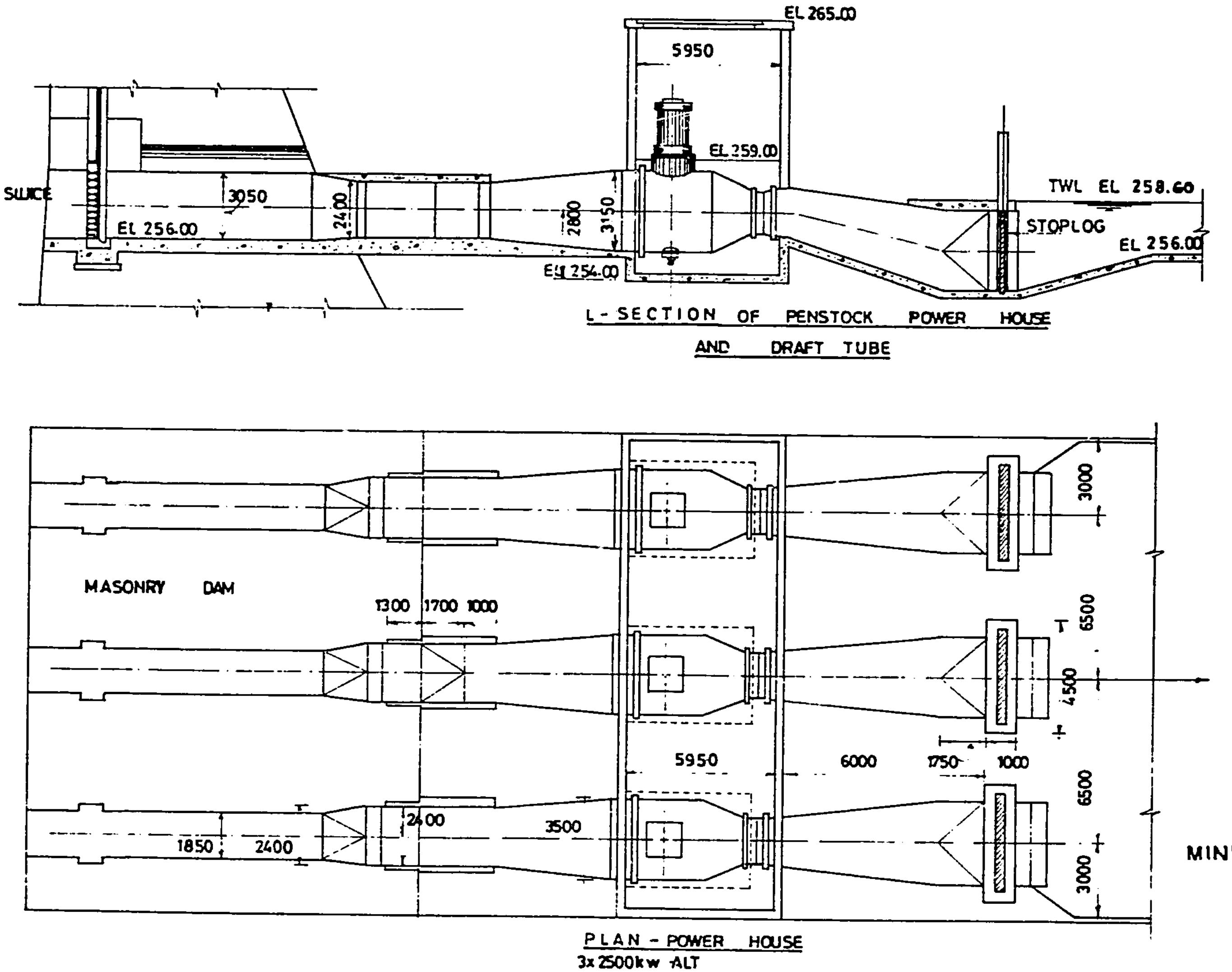

sade/w48595( 77 )






sads/w48595( 78)


EL 265.00
5.950
11400
7.370
DAM STRUCTURE
EL 259.00
EL 260.00
EL 259.45
3.050
2.400 SQUARE
3850
2.000
3910
STOP LOG
EL 255.46
EL 256.00
EL 256.00
CANAL SLUICE
SIZE 1.83 x 3.05
EL 254.50
EL 254.00
L-SECTION OF PENSTOCK
POWER HOUSE & DRAFT TUBE
1300
1.700
1.000
EL. 260.00
1.850
2.40
3810
11.50
5950
7.370
2140
2.00
HATCHWAY
0.50
EL 265.00
OPU
7.0 ODY ALT-2
EL 260.00
CANAL GUIDE WALL TOP
WALK WAY
STEPS
PROPOSED O D Y
11.00 x 7.0
ALT - 1
PLAN
2 x 3500 kw ALT
SUITABLE MODIFICATIONS SUCH AS RIM TYPE OR BELT DRIVE TO RIGHT ANGLE DRIVE MAY BE CONSIDERED WITH ASSOCIATED ADDITIONAL FLOOR SPACE IF NECESSARY LATER
ALT ARRANGEMENT FOR GENERATOR
(BELT DRIVE)
MINI HYDRO POWER PROJECT
ESMAP STUDY
LOWER BHAVANI
POWER HOUSE
ESMAP ALTERNATIVE
SHEET 4 OF 5




MINI HYDRO POWER PROJECT
ESMAP STUDY
LOWER BHAVANI
POWER HOUSE
ESMAP ALTERNATIVE
SHEET 5 OF 5



sads/w48595( 80)

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAMME

COMPLETED ACTIVITIES

| *Country* | *Activity* | *Date* | *Number* |
|---|---|---|---|
| | **SUB-SAHARAN AFRICA** | | |
| Africa Regional | Anglophone Africa Household Energy Workshop | 07/88 | 085/88 |
| | Regional Power Seminar on Reducing Electric Power System Losses in Africa | 08/88 | 087/88 |
| | Institutional Evaluation of EGL | 02/89 | 098/89 |
| | Biomass Mapping Regional Workshops | 05/89 | -- |
| | Francophone Household Energy Workshop | 08/89 | 103/89 |
| | Interafrican Electrical Engineering College: Proposals for Short- and Long-Term Development | 03/90 | 112/90 |
| | Biomass Assessment and Mapping | 03/90 | -- |
| Angola | Energy Assessment | 05/89 | 4708-ANG |
| Benin | Energy Assessment | 06/85 | 5222-BEN |
| Botswana | Energy Assessment | 09/84 | 4998-BT |
| | Pump Electrification Prefeasibility Study | 01/86 | 047/86 |
| | Review of Electricity Service Connection Policy | 07/87 | 071/87 |
| | Tuli Block Farms Electrification Study | 07/87 | 072/87 |
| | Household Energy Issues Study | 02/88 | -- |
| | Urban Household Energy Strategy Study | 05/91 | 132/91 |
| Burkina Faso | Energy Assessment | 01/86 | 5730-BUR |
| | Technical Assistance Program | 03/86 | 052/86 |
| | Urban Household Energy Strategy Study | 06/91 | 134/91 |
| Burundi | Energy Assessment | 06/82 | 3778-BU |
| | Petroleum Supply Management | 01/84 | 012/84 |
| | Status Report | 02/84 | 011/84 |
| | Presentation of Energy Projects for the Fourth Five-Year Plan (1983-1987) | 05/85 | 036/85 |
| | Improved Charcoal Cookstove Strategy | 09/85 | 042/85 |
| | Peat Utilization Project | 11/85 | 046/85 |
| Cape Verde | Energy Assessment | 08/84 | 5073-CV |
| | Household Energy Strategy Study | 02/90 | 110/90 |
| Comoros | Energy Assessment | 01/88 | 7104-COM |
| Congo | Energy Assessment | 01/88 | 6420-COB |
| | Power Development Plan | 03/90 | 106/90 |
| Côte d'Ivoire | Energy Assessment | 04/85 | 5250-IVC |
| | Improved Biomass Utilization | 04/87 | 069/87 |
| | Power System Efficiency Study | 12/87 | -- |
| Ethiopia | Energy Assessment | 07/84 | 4741-ET |
| | Power System Efficiency Study | 10/85 | 045/85 |
| | Agricultural Residue Briquetting Pilot Project | 12/86 | 062/86 |
| | Bagasse Study | 12/86 | 063/86 |
| | Cooking Efficiency Project | 12/87 | -- |
| Gabon | Energy Assessment | 07/88 | 6915-GA |

99

| Country | Activity | Date | Number |
|---|---|---|---|
| The Gambia | Energy Assessment | 11/83 | 4743-GM |
| | Solar Water Heating Retrofit Project | 02/85 | 030/85 |
| | Solar Photovoltaic Applications | 03/85 | 032/85 |
| | Petroleum Supply Management Assistance | 04/85 | 035/85 |
| Ghana | Energy Assessment | 11/86 | 6234-GH |
| | Energy Rationalization in the Industrial Sector | 06/88 | 084/88 |
| | Sawmill Residues Utilization Study | 11/88 | 074/87 |
| Guinea | Energy Assessment | 11/86 | 6137-GUI |
| Guinea-Bissau | Energy Assessment | 08/84 | 5083-GUB |
| | Recommended Technical Assistance Projects | 04/85 | 033/85 |
| | Management Options for the Electric Power and Water Supply Subsectors | 02/90 | 100/90 |
| | Power and Water Institutional Restructuring (French) | 04/91 | 118/91 |
| Kenya | Energy Assessment | 05/82 | 3800-KE |
| | Power System Efficiency Study | 03/84 | 014/84 |
| | Status Report | 05/84 | 016/84 |
| | Coal Conversion Action Plan | 02/87 | -- |
| | Solar Water Heating Study | 02/87 | 066/87 |
| | Peri-Urban Woodfuel Development | 10/87 | 076/87 |
| | Power Master Plan | 11/87 | -- |
| Lesotho | Energy Assessment | 01/84 | 4676-LSO |
| Liberia | Energy Assessment | 12/84 | 5279-LBR |
| | Recommended Technical Assistance Projects | 06/85 | 038/85 |
| | Power System Efficiency Study | 12/87 | 081/87 |
| Madagascar | Energy Assessment | 01/87 | 5700-MAG |
| | Power System Efficiency Study | 12/87 | 075/87 |
| Malawi | Energy Assessment | 08/82 | 3903-MAL |
| | Technical Assistance to Improve the Efficiency of Fuelwood Use in the Tobacco Industry | 11/83 | 009/83 |
| | Status Report | 01/84 | 013/84 |
| Islamic Republic of Mauritania | Energy Assessment | 04/85 | 5224-MAU |
| | Household Energy Strategy Study | 07/90 | 123/90 |
| Mauritius | Energy Assessment | 12/81 | 3510-MAS |
| | Status Report | 10/83 | 008/83 |
| | Power System Efficiency Audit | 05/87 | 070/87 |
| | Bagasse Power Potential | 10/87 | 077/87 |
| Mozambique | Energy Assessment | 01/87 | 6128-MOZ |
| | Household Electricity Utilization Study | 03/90 | 113/90 |
| Niger | Energy Assessment | 05/84 | 4642-NIR |
| | Status Report | 02/86 | 051/86 |
| | Improved Stoves Project | 12/87 | 080/87 |
| | Household Energy Conservation and Substitution | 01/88 | 082/88 |
| Nigeria | Energy Assessment | 08/83 | 4440-UNI |
| Rwanda | Energy Assessment | 06/82 | 3779-RW |
| | Energy Assessment | 07/91 | 8017-RW |
| | Status Report | 05/84 | 017/84 |
| | Improved Charcoal Cookstove Strategy | 08/86 | 059/86 |
| | Improved Charcoal Production Techniques | 02/87 | 065/87 |

·100

| *Country* | *Activity* | *Date* | *Number* |
|---|---|---|---|
| Sao Tome and Principe | Energy Assessment | 10/85 | 5803-STP |
| Senegal | Energy Assessment | 07/83 | 4182-SE |
| | Status Report | 10/84 | 025/84 |
| | Industrial Energy Conservation Study | 05/85 | 037/85 |
| | Preparatory Assistance for Donor Meeting | 04/86 | 056/86 |
| | Urban Household Energy Strategy | 02/89 | 096/89 |
| Seychelles | Energy Assessment | 01/84 | 4693-SEY |
| | Electric Power System Efficiency Study | 08/84 | 021/84 |
| Sierra Leone | Energy Assessment | 10/87 | 6597-SL |
| Somalia | Energy Assessment | 12/85 | 5796-SO |
| Sudan | Management Assistance to the Ministry of Energy and Mining | 05/83 | 003/83 |
| | Energy Assessment | 07/83 | 4511-SU |
| | Power System Efficiency Study | 06/84 | 018/84 |
| | Status Report | 11/84 | 026/84 |
| | Wood Energy/Forestry Feasibility | 07/87 | 073/87 |
| Swaziland | Energy Assessment | 02/87 | 6262-SW |
| Tanzania | Energy Assessment | 11/84 | 4969-TA |
| | Peri-Urban Woodfuels Feasibility Study | 08/88 | 086/88 |
| | Tobacco Curing Efficiency Study | 05/89 | 102/89 |
| | Remote Sensing and Mapping of Woodlands | 06/90 | -- |
| | Industrial Energy Efficiency Technical Assistance | 08/90 | 122/90 |
| Togo | Energy Assessment | 06/85 | 5221-TO |
| | Wood Recovery in the Nangbeto Lake | 04/86 | 055/86 |
| | Power Efficiency Improvement | 12/87 | 078/87 |
| Uganda | Energy Assessment | 07/83 | 4453-UG |
| | Status Report | 08/84 | 020/84 |
| | Institutional Review of the Energy Sector | 01/85 | 029/85 |
| | Energy Efficiency in Tobacco Curing Industry | 02/86 | 049/86 |
| | Fuelwood/Forestry Feasibility Study | 03/86 | 053/86 |
| | Power System Efficiency Study | 12/88 | 092/88 |
| | Energy Efficiency Improvement in the Brick and Tile Industry | 02/89 | 097/89 |
| | Tobacco Curing Pilot Project | 03/89 | UNDP Terminal Report |
| Zaire | Energy Assessment | 05/86 | 5837-ZR |
| Zambia | Energy Assessment | 01/83 | 4110-ZA |
| | Status Report | 08/85 | 039/85 |
| | Energy Sector Institutional Review | 11/86 | 060/86 |
| | Power Subsector Efficiency Study | 02/89 | 093/88 |
| | Energy Strategy Study | 02/89 | 094/88 |
| | Urban Household Energy Strategy Study | 08/90 | 121/90 |
| Zimbabwe | Energy Assessment | 06/82 | 3765-ZIM |
| | Power System Efficiency Study | 06/83 | 005/83 |
| | Status Report | 08/84 | 019/84 |
| | Power Sector Management Assistance Project | 04/85 | 034/85 |
| | Petroleum Management Assistance | 12/89 | 109/89 |
| | Power Sector Management Institution Building | 09/89 | -- |
| | Charcoal Utilization Prefeasibility Study | 06/90 | 119/90 |

| *Country* | *Activity* | *Date* | *Number* |
|---|---|---|---|

## ASIA AND THE PACIFIC

| | | | |
|---|---|---|---|
| Asia Regional | Pacific Household and Rural Energy Seminar | 11/90 | -- |
| Bangladesh | Energy Assessment | 10/82 | 3873-BD |
| | Priority Investment Program | 05/83 | 002/83 |
| | Status Report | 04/84 | 015/84 |
| | Power System Efficiency Study | 02/85 | 031/85 |
| | Small Scale Uses of Gas Prefeasibility Study | 12/88 | -- |
| China | County-Level Rural Energy Assessments | 05/89 | 101/89 |
| | Fuelwood Forestry Preinvestment Study | 12/89 | 105/89 |
| Fiji | Energy Assessment | 06/83 | 4462-FIJ |
| India | Opportunities for Commercialization of Nonconventional Energy Systems | 11/88 | 091/88 |
| | Maharashtra Bagasse Energy Efficiency Project | 05/91 | 120/91 |
| | Mini-Hydro Development on Irrigation Dams and Canal Drops Vols. I, II and III | 07/91 | 131/91 |
| Indonesia | Energy Assessment | 11/81 | 3543-IND |
| | Status Report | 09/84 | 022/84 |
| | Power Generation Efficiency Study | 02/86 | 050/86 |
| | Energy Efficiency in the Brick, Tile and Lime Industries | 04/87 | 067/87 |
| | Diesel Generating Plant Efficiency Study | 12/88 | 095/88 |
| | Urban Household Energy Strategy Study | 02/90 | 107/90 |
| | Biomass Gasifier Preinvestment Study Vols. I & II | 12/90 | 124/90 |
| Malaysia | Sabah Power System Efficiency Study | 03/87 | 068/87 |
| Myanmar | Energy Assessment | 06/85 | 5416-BA |
| Nepal | Energy Assessment | 08/83 | 4474-NEP |
| | Status Report | 01/85 | 028/84 |
| Papua New Guinea | Energy Assessment | 06/82 | 3882-PNG |
| | Status Report | 07/83 | 006/83 |
| | Energy Strategy Paper | -- | -- |
| | Institutional Review in the Energy Sector | 10/84 | 023/84 |
| | Power Tariff Study | 10/84 | 024/84 |
| Solomon Islands | Energy Assessment | 06/83 | 4404-SOL |
| South Pacific | Petroleum Transport in the South Pacific | 05/86 | -- |
| Sri Lanka | Energy Assessment | 05/82 | 3792-CE |
| | Power System Loss Reduction Study | 07/83 | 007/83 |
| | Status Report | 01/84 | 010/84 |
| | Industrial Energy Conservation Study | 03/86 | 054/86 |
| Thailand | Energy Assessment | 09/85 | 5793-TH |
| | Rural Energy Issues and Options | 09/85 | 044/85 |
| | Accelerated Dissemination of Improved Stoves and Charcoal Kilns | 09/87 | 079/87 |
| | Northeast Region Village Forestry and Woodfuels Preinvestment Study | 02/88 | 083/88 |
| | Impact of Lower Oil Prices | 08/88 | -- |
| | Coal Development and Utilization Study | 10/89 | -- |
| Tonga | Energy Assessment | 06/85 | 5498-TON |
| Vanuatu | Energy Assessment | 06/85 | 5577-VA |
| Western Samoa | Energy Assessment | 06/85 | 5497-WSO |

- 102

| Country | Activity | Date | Number |
|---|---|---|---|
| | **EUROPE, MIDDLE EAST AND NORTH AFRICA (EMENA)** | | |
| Morocco | Energy Assessment | 03/84 | 4157-MOR |
| | Status Report | 01/86 | 048/86 |
| Pakistan | Household Energy Assessment | 05/88 | -- |
| | Assessment of Photovoltaic Programs, Applications, and Markets | 10/89 | 103/89 |
| Portugal | Energy Assessment | 04/84 | 4824-PO |
| Syria | Energy Assessment | 05/86 | 5822-SYR |
| | Electric Power Efficiency Study | 09/88 | 089/88 |
| | Energy Efficiency Improvement in the Cement Sector | 04/89 | 099/89 |
| | Energy Efficiency Improvement in the Fertilizer Sector | 06/90 | 115/90 |
| Tunisia | Fuel Substitution | 03/90 | -- |
| Turkey | Energy Assessment | 03/83 | 3877-TU |
| Yemen | Energy Assessment | 12/84 | 4892-YAR |
| | Energy Investment Priorities | 02/87 | 6376-YAR |
| | Household Energy Strategy Study Phase I | 03/91 | 126/91 |
| | **LATIN AMERICA AND THE CARIBBEAN (LAC)** | | |
| LAC Regional | Regional Seminar on Electric Power System Loss Reduction in the Caribbean | 07/89 | -- |
| Bolivia | Energy Assessment | 04/83 | 4213-BO |
| | National Energy Plan | 12/87 | -- |
| | National Energy Plan (Spanish) | 08/91 | 131/91 |
| | La Paz Private Power Technical Assistance | 11/90 | 111/90 |
| | Natural Gas Distribution | 03/91 | 125/91 |
| | Prefeasibility Evaluation Rural Electrification and Demand Assessment | 04/91 | 129/91 |
| Chile | Energy Sector Review | 08/88 | 7129-CH |
| Colombia | Energy Strategy Paper | 12/86 | -- |
| Costa Rica | Energy Assessment | 01/84 | 4655-CR |
| | Recommended Technical Assistance Projects | 11/84 | 027/84 |
| | Forest Residues Utilization Study | 02/90 | 108/90 |
| Dominican Republic | Energy Assessment | 05/91 | 8234-DO |
| Ecuador | Energy Assessment | 12/85 | 5865-EC |
| | Energy Strategy Phase I | 07/88 | -- |
| | Energy Strategy | 04/91 | -- |
| Haiti | Energy Assessment | 06/82 | 3672-HA |
| | Status Report | 08/85 | 041/85 |
| Honduras | Energy Assessment | 08/87 | 6476-HO |
| | Petroleum Supply Management | 03/91 | 128/91 |
| Jamaica | Energy Assessment | 04/85 | 5466-JM |
| | Petroleum Procurement, Refining, and Distribution Study | 11/86 | 061/86 |
| | Energy Efficiency Building Code Phase I | 03/88 | -- |
| | Energy Efficiency Standards and Labels Phase I | 03/88 | -- |
| | Management Information System Phase I | 03/88 | -- |
| | Charcoal Production Project | 09/88 | 090/88 |
| | FIDCO Sawmill Residues Utilization Study | 09/88 | 088/88 |

| *Country* | *Activity* | *Date* | *Number* |
|---|---|---|---|
| Mexico | Improved Charcoal Production Within Forest Management for the State of Veracruz | 08/91 | 138/91 |
| Panama | Power System Efficiency Study | 06/83 | 004/83 |
| Paraguay | Energy Assessment | 10/84 | 5145-PA |
| | Recommended Technical Assistance Projects | 09/85 | -- |
| | Status Report | 09/85 | 043/85 |
| Peru | Energy Assessment | 01/84 | 4677-PE |
| | Status Report | 08/85 | 040/85 |
| | Proposal for a Stove Dissemination Program in the Sierra | 02/87 | 064/87 |
| | Energy Strategy | 12/90 | -- |
| Saint Lucia | Energy Assessment | 09/84 | 5111-SLU |
| St. Vincent and the Grenadines | Energy Assessment | 09/84 | 5103-STV |
| Trinidad and Tobago | Energy Assessment | 12/85 | 5930-TR |

## GLOBAL

| | | | |
|---|---|---|---|
| | Energy End Use Efficiency: Research and Strategy | 11/89 | -- |
| | Guidelines for Utility Customer Management and Metering | 07/91 | -- |
| | Women and Energy--A Resource Guide The International Network: Policies and Experience | 04/90 | -- |

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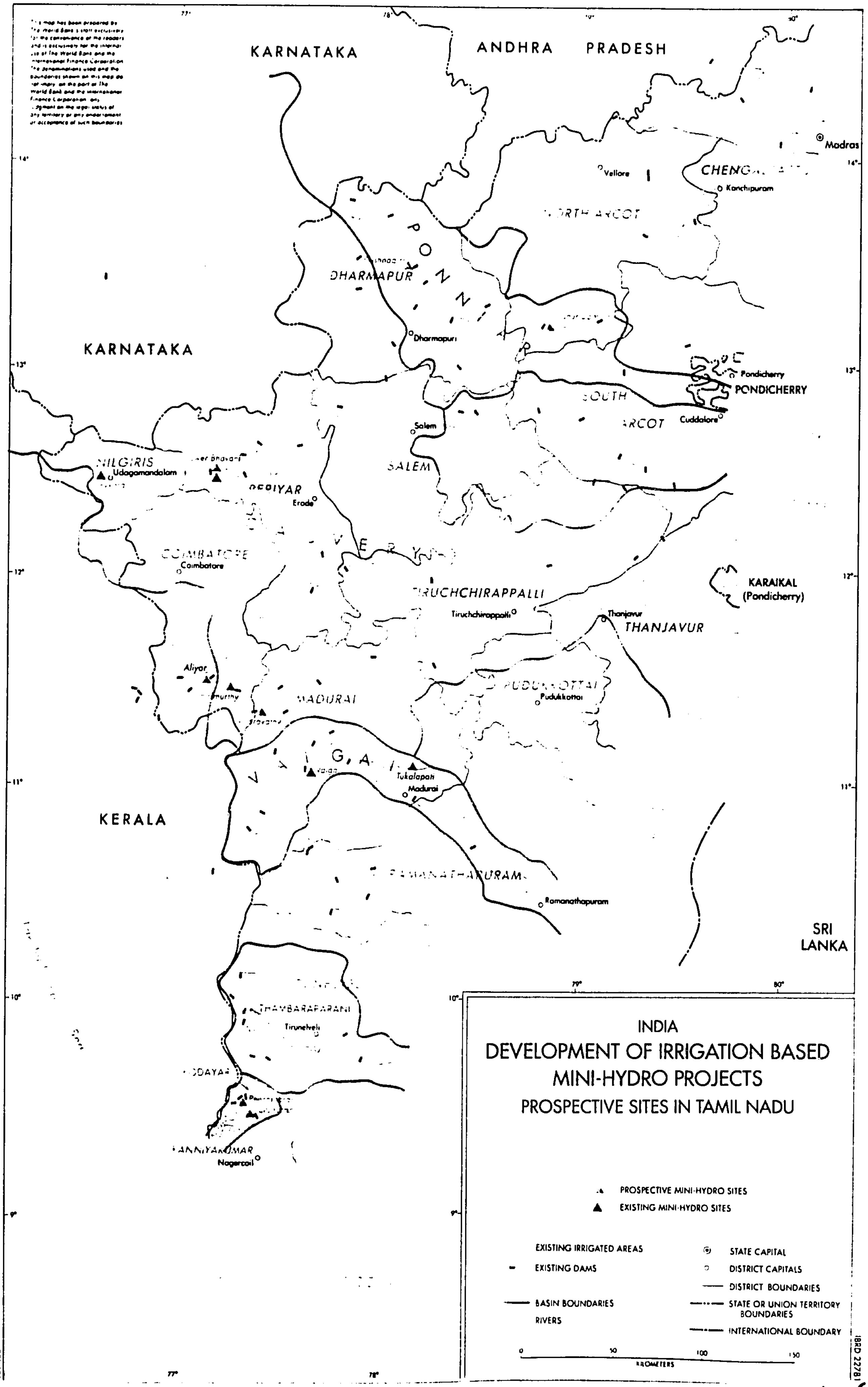
104


INDIA
DEVELOPMENT OF IRRIGATION BASED
MINI-HYDRO PROJECTS
PROSPECTIVE SITES IN TAMIL NADU
PROSPECTIVE MINI-HYDRO SITES
EXISTING MINI-HYDRO SITES
EXISTING IRRIGATED AREAS
EXISTING DAMS
BASIN BOUNDARIES
RIVERS
STATE CAPITAL
DISTRICT CAPITALS
DISTRICT BOUNDARIES
STATE OR UNION TERRITORY BOUNDARIES
INTERNATIONAL BOUNDARY
0
50
100
150
KILOMETERS
KARNATAKA
ANDHRA PRADESH
KARNATAKA
KERALA
SRI LANKA
Madras
Vellore
Kanchipuram
DHARMAPUR
Dharmapuri
Pondicherry
PONDICHERRY
SOUTH
ARCOT
Cuddalore
Salem
SALEM
NILGIRIS
Udagamandalam
PERIYAR
Erode
Coimbatore
TIRUCHCHIRAPPALLI
Tiruchchirappalli
Thanjavur
THANJAVUR
KARAIKAL
(Pondicherry)
Aliyar
MADURAI
Pudukkottai
V A I G A I
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Madurai
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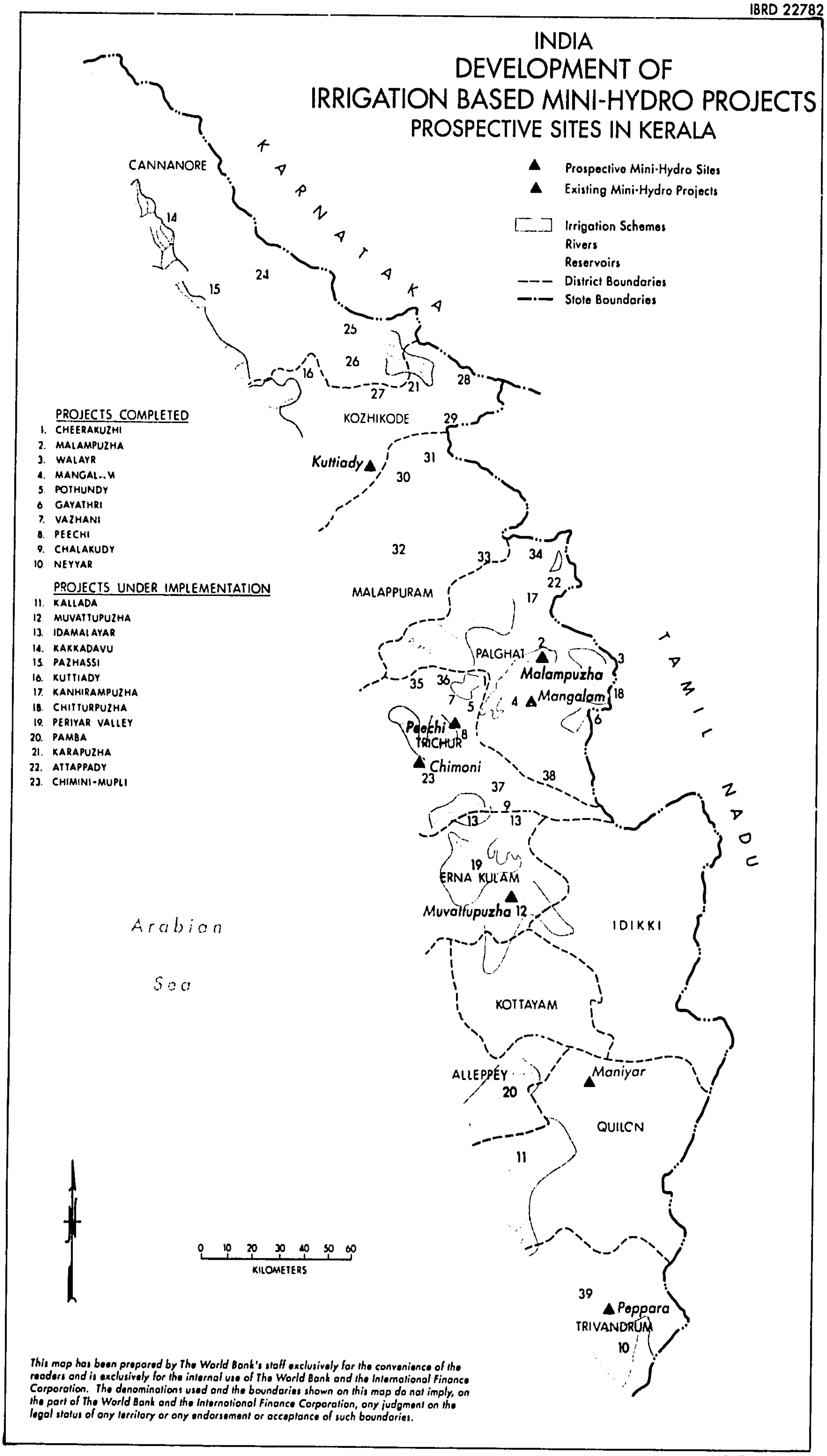
Tirunelveli
Nagercoil
IBRD 22781

IBRD 22782

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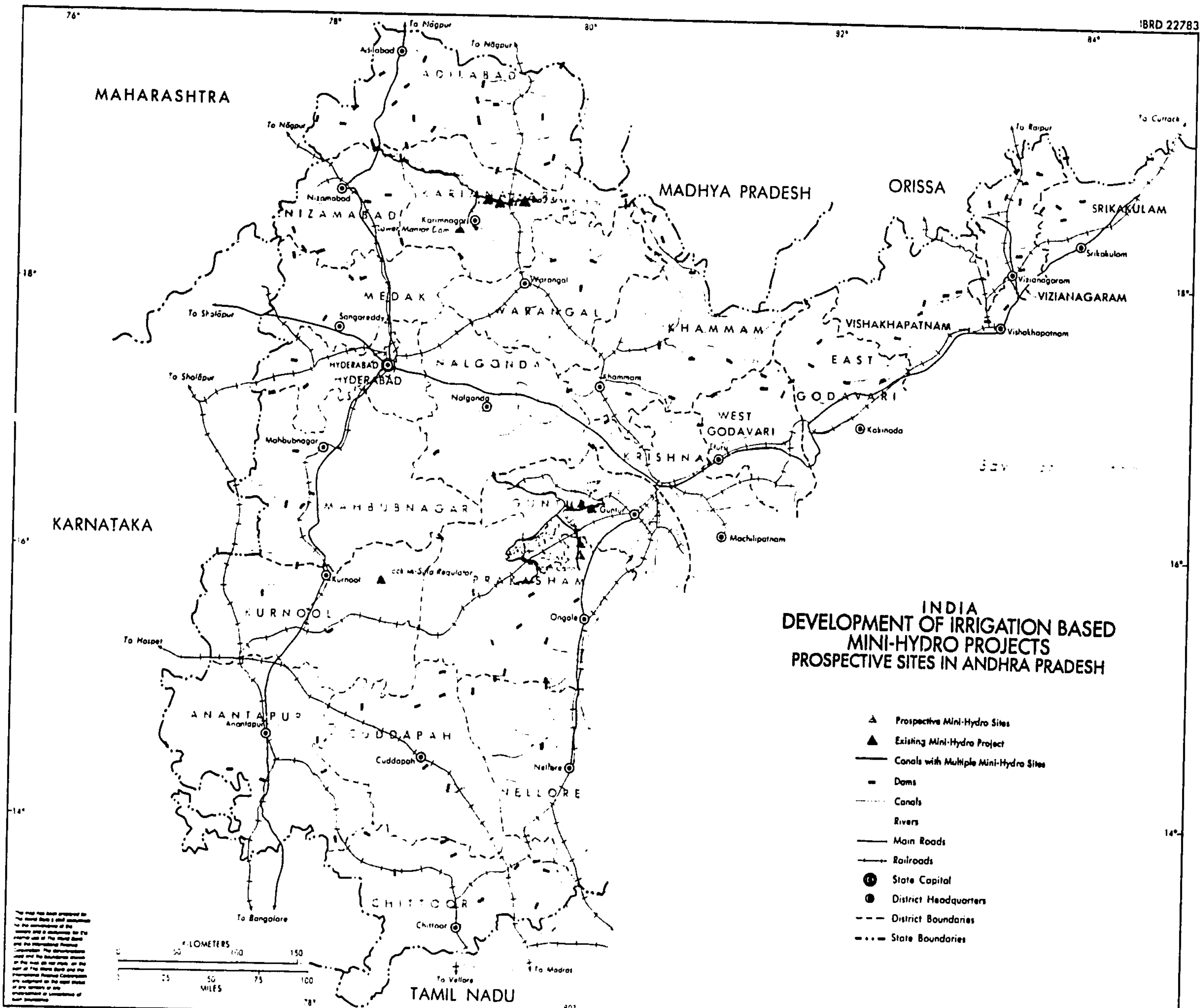
106



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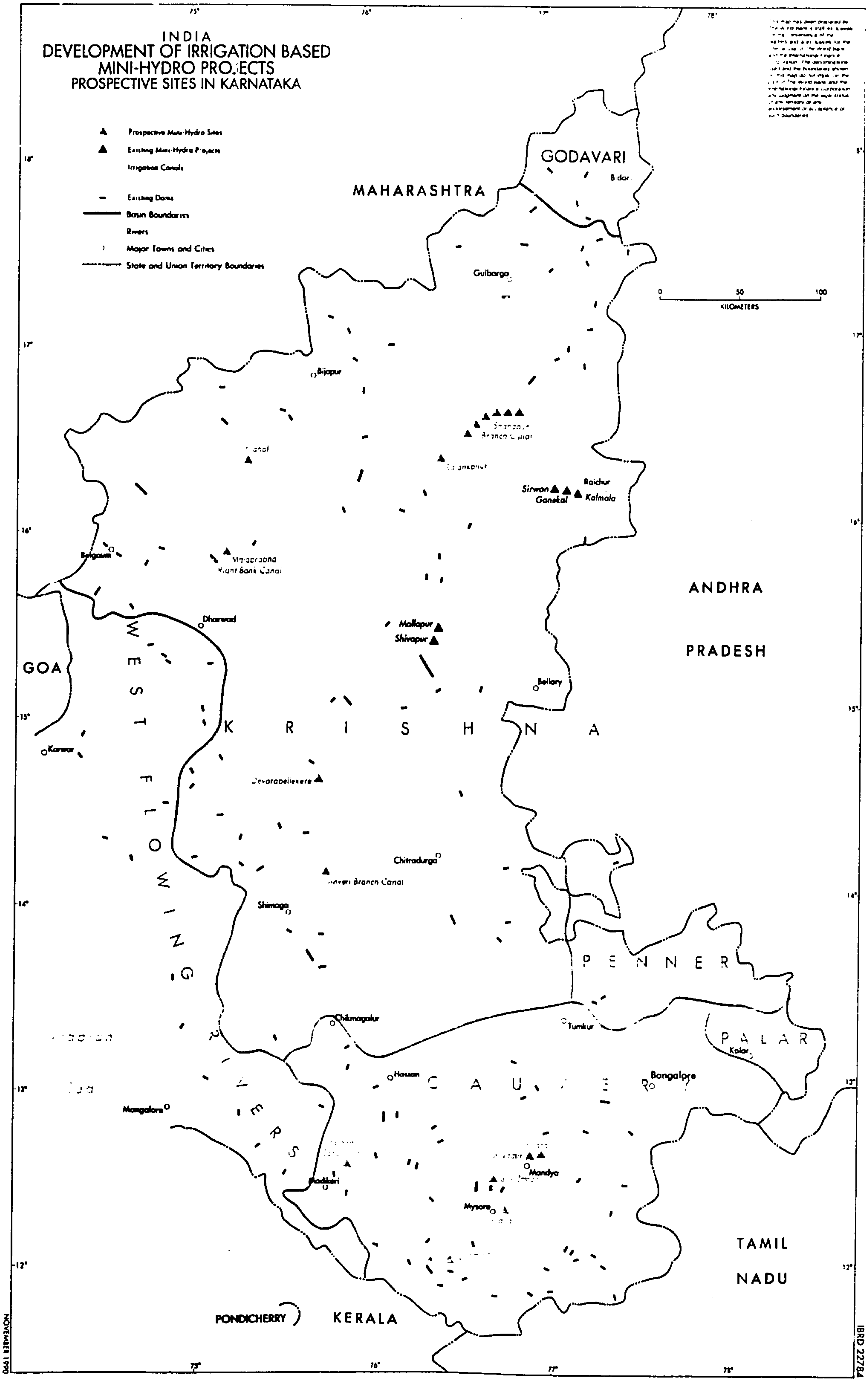
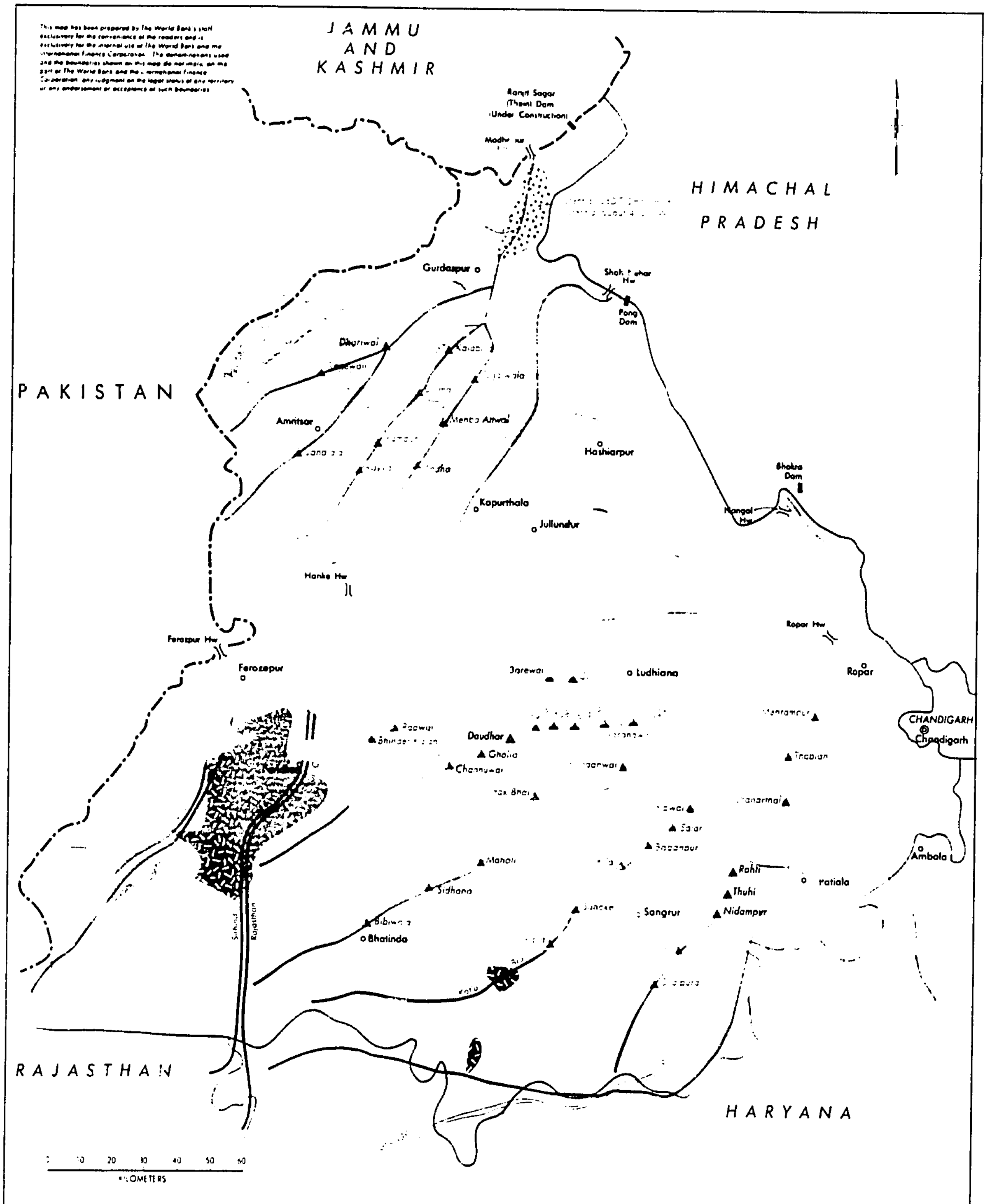
107


INDIA
DEVELOPMENT OF IRRIGATION BASED
MINI-HYDRO PROJECTS
PROSPECTIVE SITES IN KARNATAKA
Prospective Mini-Hydro Sites
Existing Mini-Hydro Projects
Irrigation Canals
Existing Dams
Basin Boundaries
Rivers
Major Towns and Cities
State and Union Territory Boundaries
0
50
100
KILOMETERS
GODAVARI
Bidar
MAHARASHTRA
Gulbarga
Bijapur
Raichur
Sirwan
Ganekal
Kalmala
Belgaum
Dharwad
Mallapur
Shivapur
GOA
Bellary
Karwar
ANDHRA
PRADESH
K R I S H N A
W E S T F L O W I N G R I V E R S
Chitradurga
Shimoga
P E N N E R
Chikmagalur
Tumkur
P A L A R
Kolar
Hassan
C A U V E R Y
Bangalore
Mangalore
Mandya
Madikeri
Mysore
TAMIL
NADU
PONDICHERRY
KERALA
75°
76°
77°
78°
18°
17°
16°
15°
14°
13°
12°
NOVEMBER 1990
IBRD 22784




# INDIA
# DEVELOPMENT OF IRRIGATION BASED MINI-HYDRO PROJECTS
## PROSPECTIVE SITES IN PUNJAB

- Prospective Mini-Hydro Sites
- Existing Mini-Hydro Projects
- Proposed Small Hydro Sites
- Existing Main and Branch Canals
- Existing Distributory Canals
- Dam Sites
- Headworks
- Waterlogged Areas
- Saline Areas
- Rivers
- State Capital
- Towns and Villages
- State or Union Territory Boundaries
- International Boundaries

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